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of

THE ROYAL AERONAUTICAL SOCIETY

APRIL 1956

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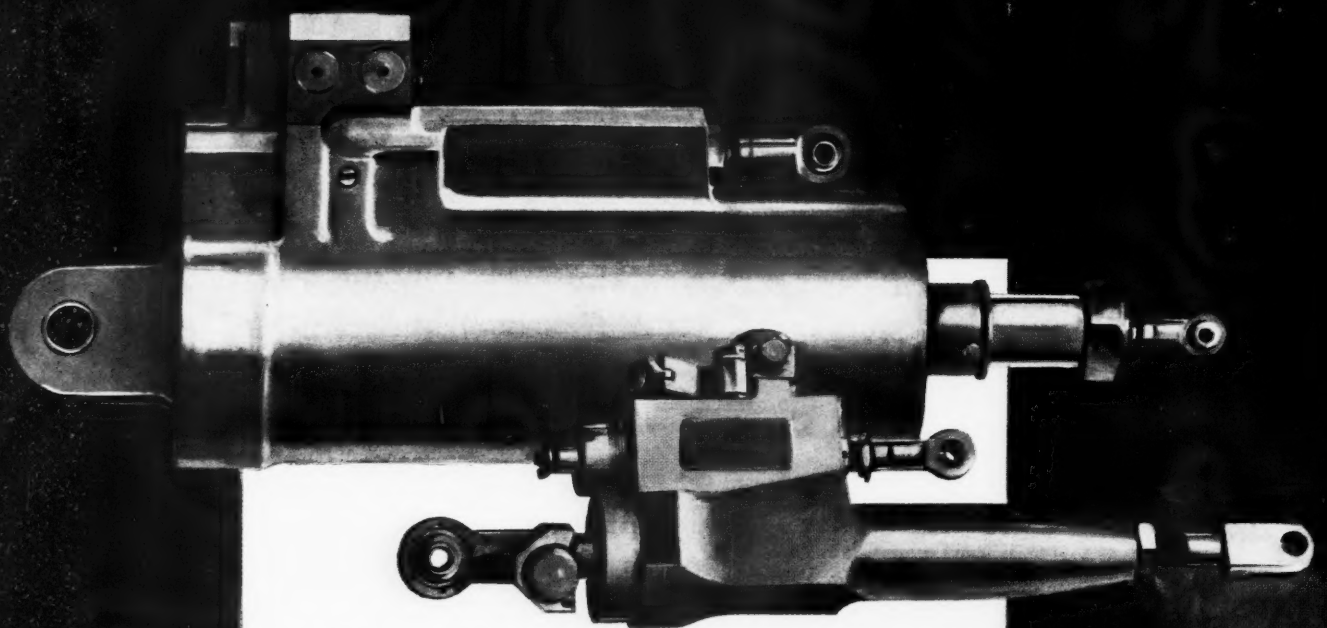

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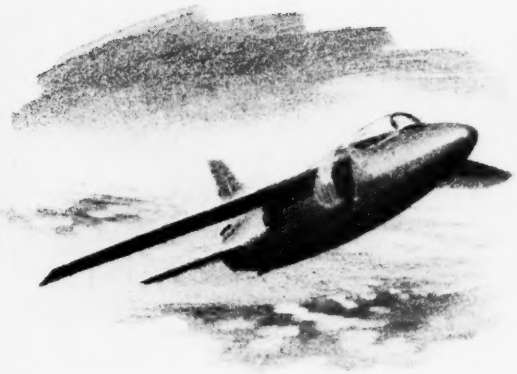

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TACTICAL:

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12 × 3-in. rockets, or
two Napalm bombs
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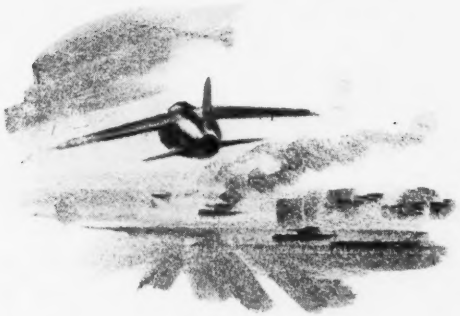
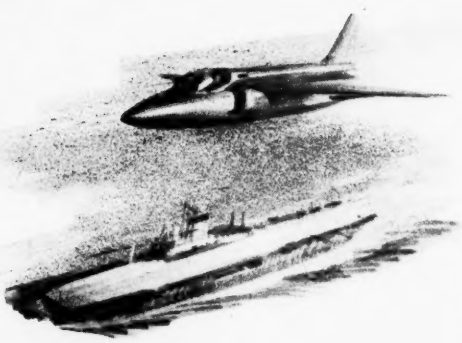
18 3-in. rockets
or
6 × 3-in. rockets and
2 × 500 lb. bombs.

} and 2 × 60 gal. drop tanks.





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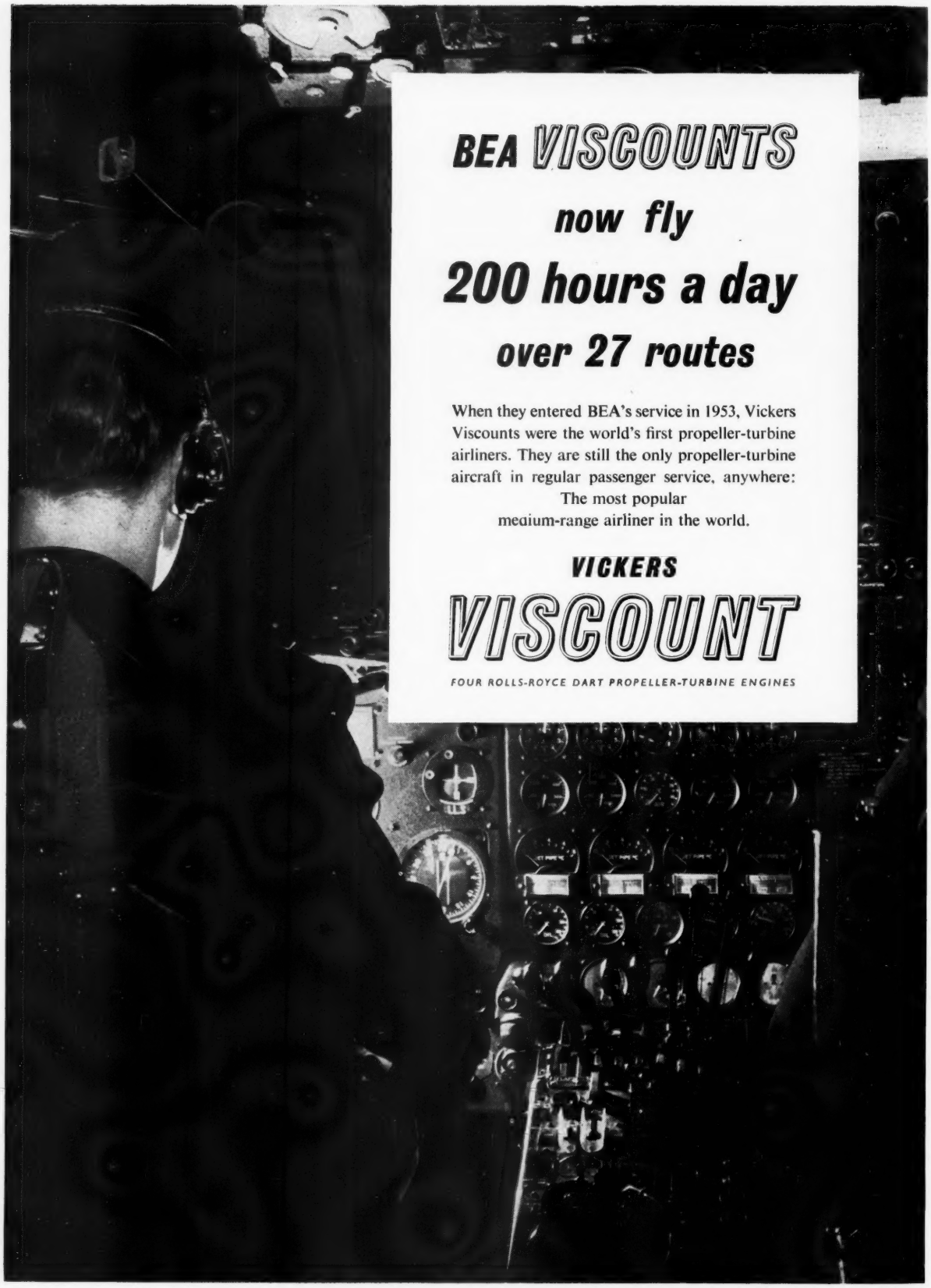

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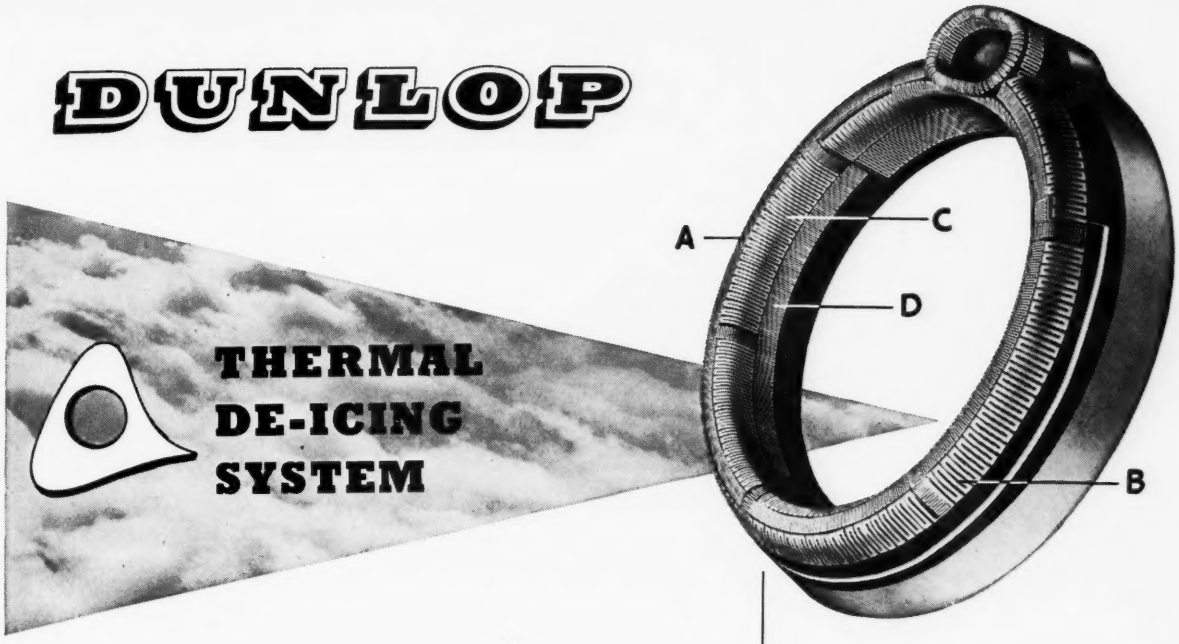

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3. Each circuit is "tailored" to suit its particular working conditions.
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* *A typical application of a Dunlop thermal de-icing mat to the intake duct of a Rolls-Royce 'Dart' engine. Circuit A applies continuous heat of highest intensity to the leading edge of intake. Circuits B and C are cyclic in operation and apply a lesser degree of heat to areas adjacent to the leading edge.*
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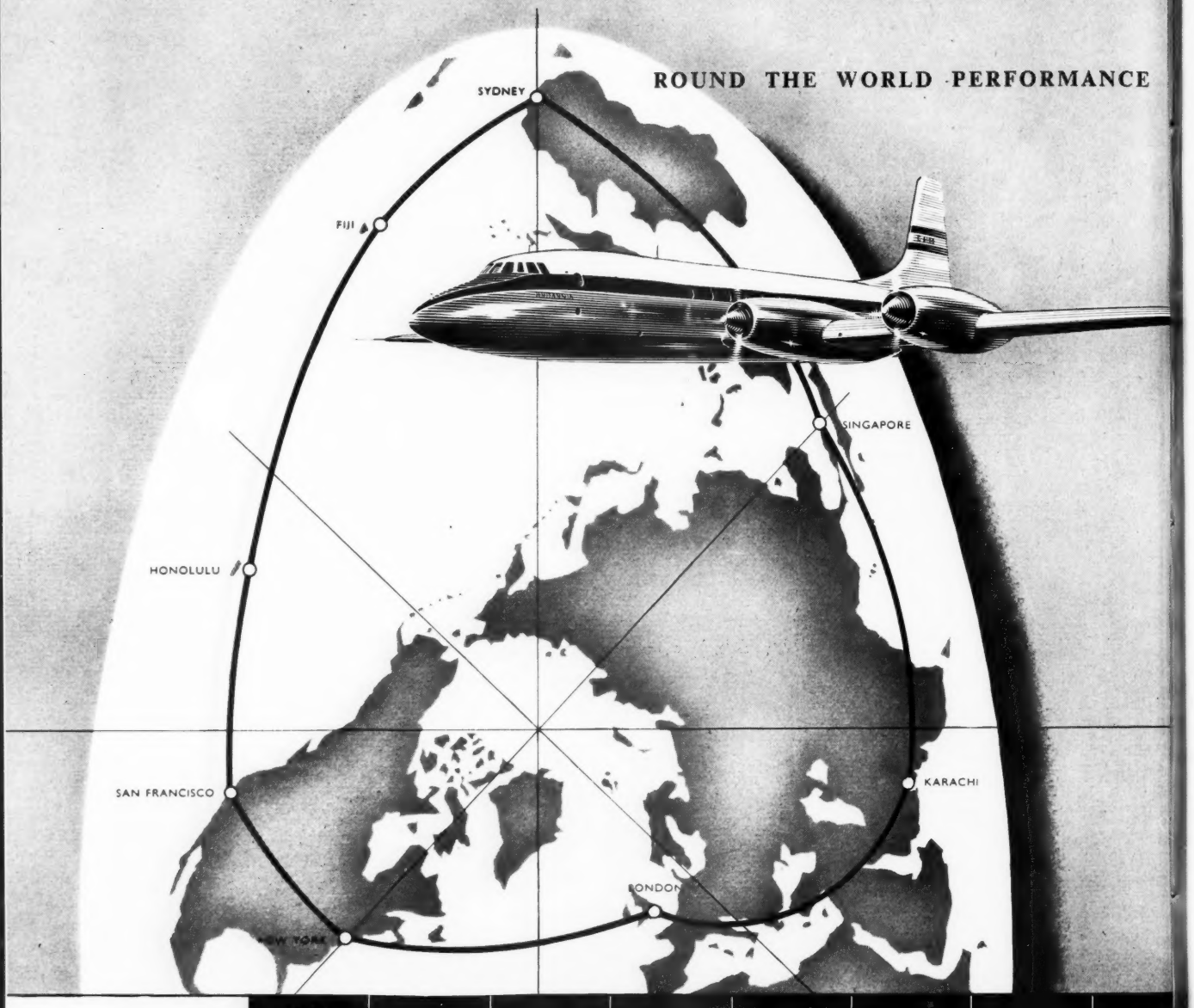

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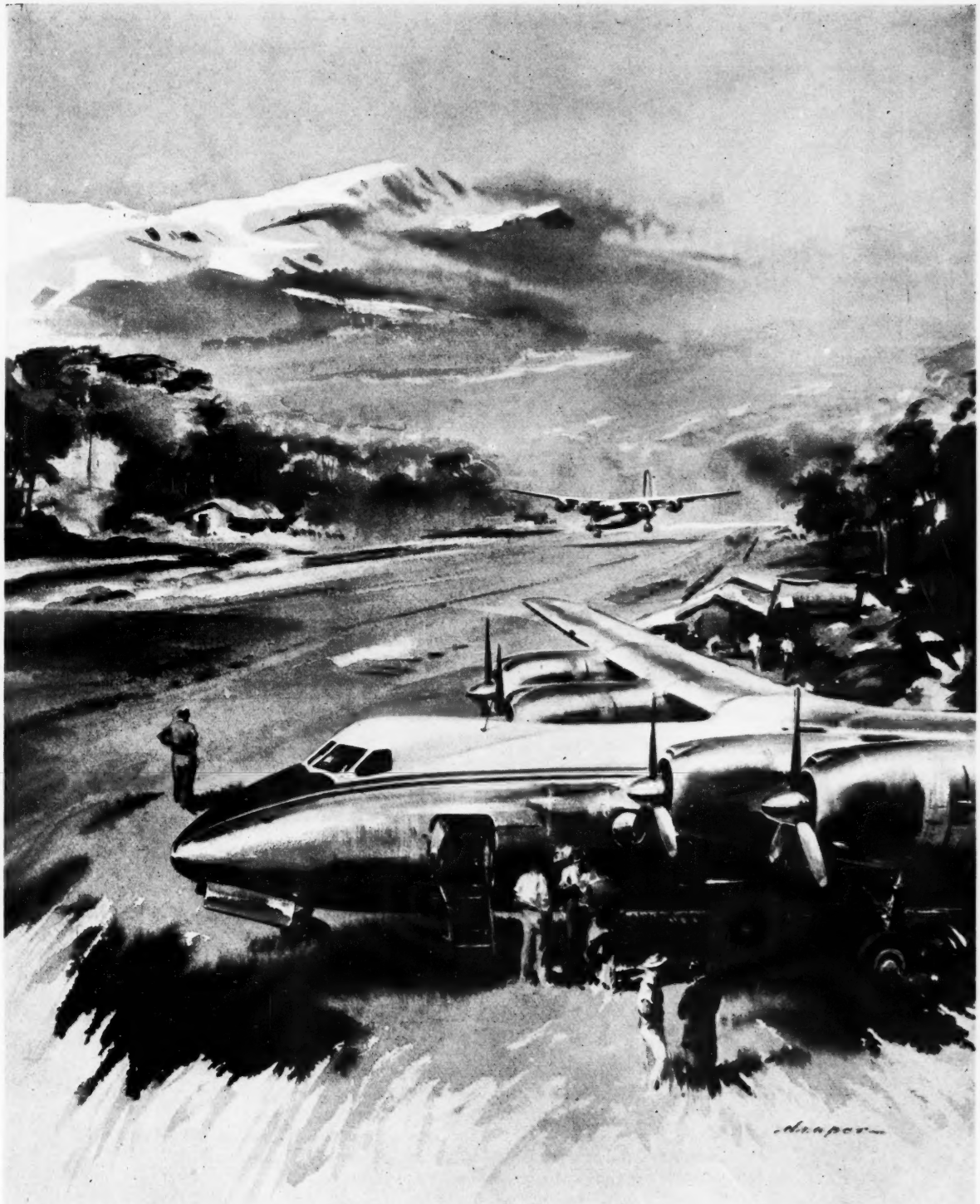

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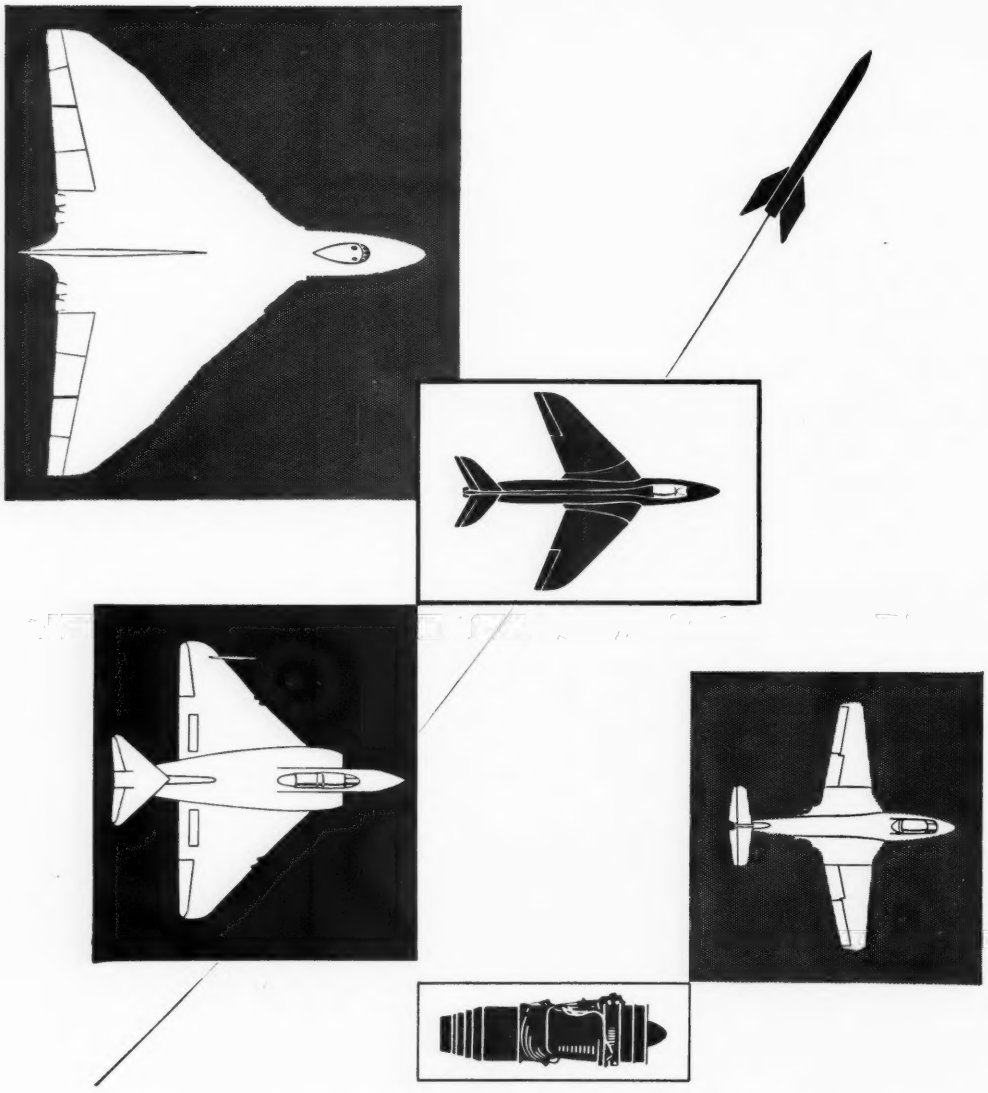

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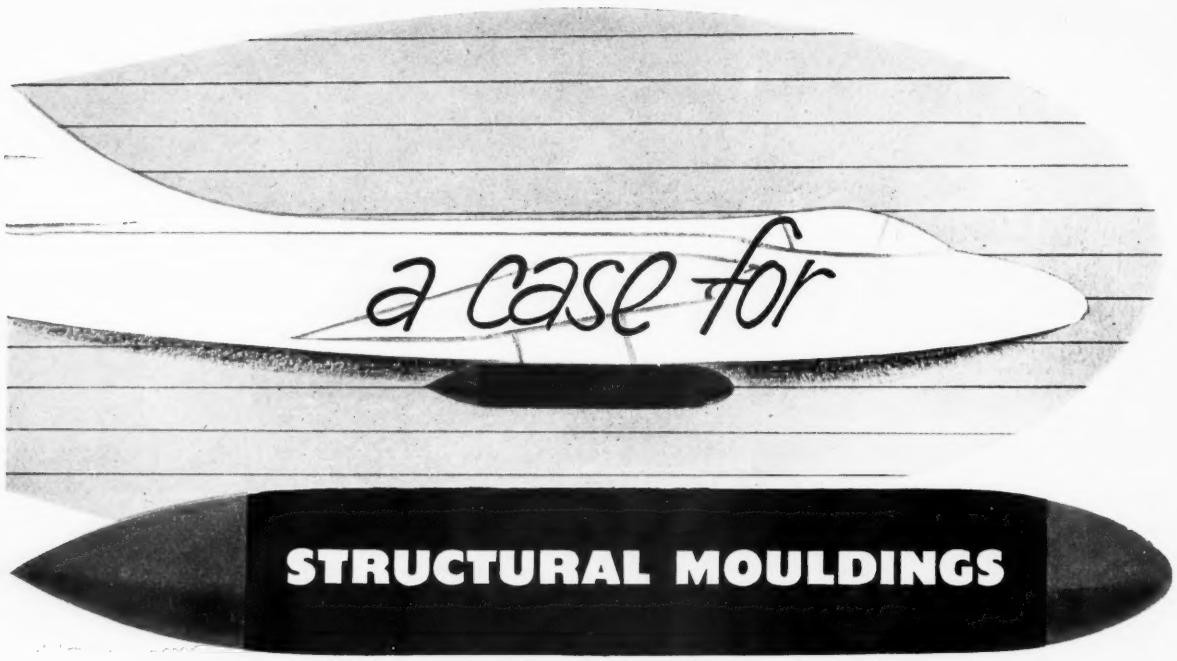

It is true that, important though they undoubtedly are, current applications for structural mouldings remain on a somewhat restricted basis. Can that basis be broadened—can the properties of polyester resins be so improved that they can meet the stringent specifications for more critical applications? That is a problem engaging the constant attention of B.I.P.'s Research Chemists and Development Engineers who, in close collaboration with aircraft constructors, are ever seeking to provide new, more efficient polyester resins for high duty service. A recent result of their work is seen in Beetle Polyester Resin 669, mouldings from which withstand temperatures up to 500° F.

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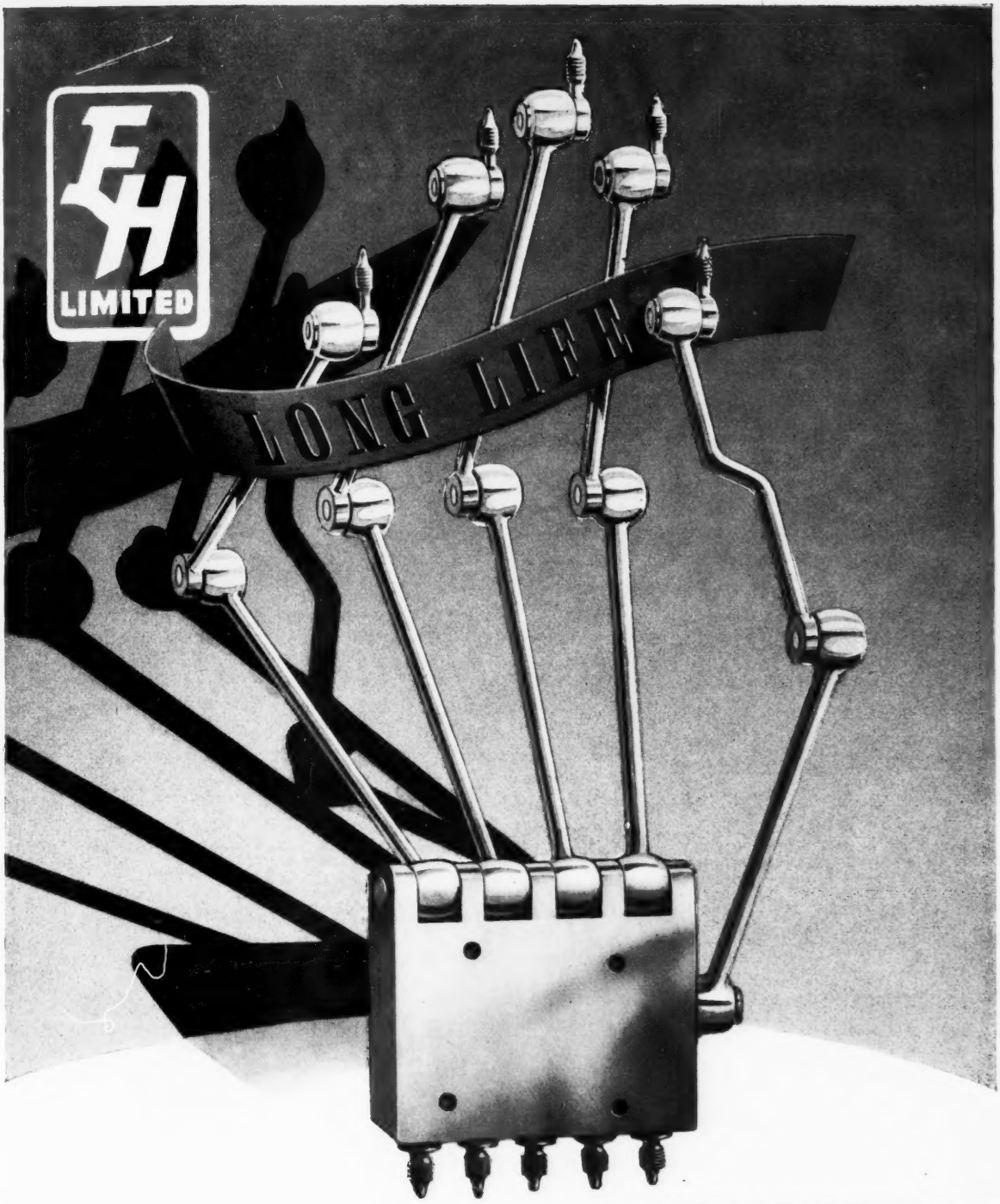

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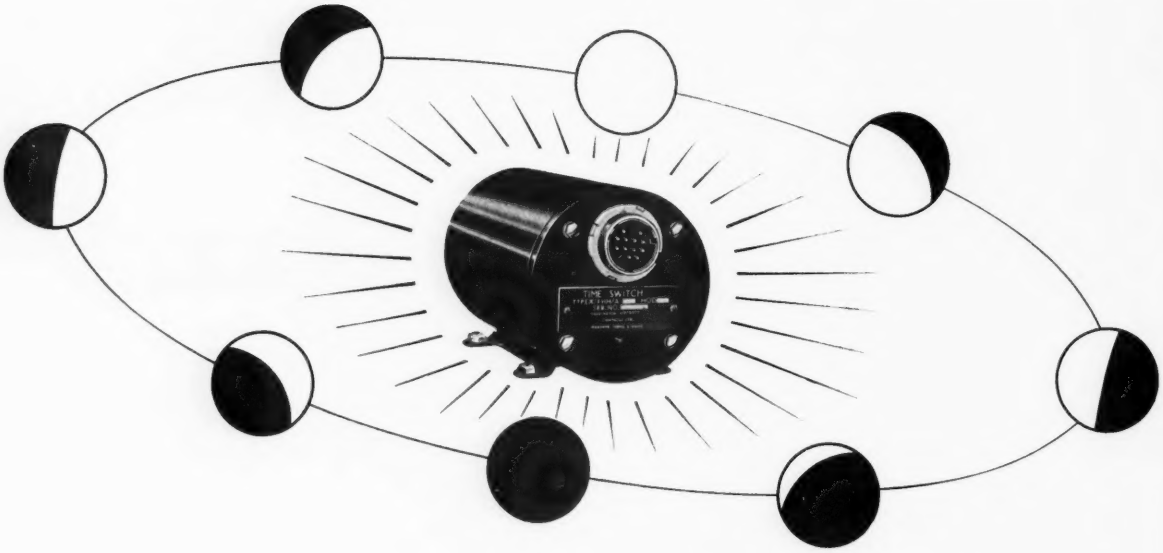

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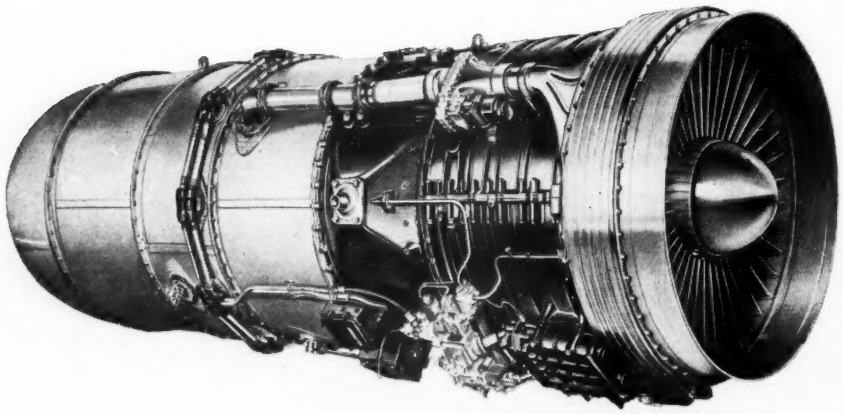

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Westland Aircraft Ltd., Yeovil.

NOTICES

An annual sum of £250 is available for premium awards for papers, including Technical Notes, published in the Journal. Members and non-members of the Society are invited to submit papers on any aspect of aeronautics

Nomination of Candidates for Council

The following is an extract from the By-Laws:—

"The Twenty-one ordinary members (of the Council) shall be nominated and elected from among the members of the Society. At the date of their election at least ten shall be Fellows, and one at least shall be in each of the following classes: Associate Fellow, Associate and Graduate.

"Of the ordinary members of the Council, that number necessary to create seven vacancies shall retire annually. The retiring members shall be those with the longest service since their last election but they shall be eligible for re-election.

"Nominations of candidates for election to the Council must be received by the Secretary not later than 10th April in each year and shall include statements in writing by the candidates that they are willing to serve. The nomination forms shall be signed by one proposer and two seconders, all of whom shall be Voters."

Nomination forms may be obtained on application to the Secretary.

All-Day Section Lecture and Discussion on Supersonic Flight

The attention of members is drawn to the All-Day Section Lecture and Discussion on Supersonic Flight to be held on Wednesday, 9th May 1956, at 10.0 a.m., at the Institution of Civil Engineers, Gt. George Street, S.W.1. Four short papers to give an introduction to some of the general problems of supersonic flight will be presented by Mr. P. J. Duncton, Mr. A. V. Cleaver, Mr. D. J. Farrer and Mr. H. H. Gardner. The Chair will be taken by Mr. G. W. H. Gardner.

Graduates' and Students' Section—Visits

A visit has been arranged to the United States Third Air Force at the R.A.F. Station, Manston, Kent, for Saturday, 19th May 1956. This is the occasion of Armed Forces Day, and we have been promised a specially conducted tour round the aircraft. A fully representative selection of aircraft based in the United Kingdom will be on show, and there will be helicopter rescue demonstrations.

Applications should be made as soon as possible to the Hon. Visits Secretary, Mr. N. K. Benson, 14 Wakering Road, Barking, Essex.

Production Exhibition and Conference

The Production Exhibition and Conference, which is sponsored by the Institution of Production Engineers, will be held in the Grand Hall at Olympia from 23rd to 31st May 1956. The main sections of the Exhibition will be: Research and Development, Information, Training and Education, Human Relations and Welfare, Aids to Production, Materials, Methods, Services, Automation, Exhibition enquiries should be addressed to: Andry Montgomery Ltd., 32 Millbank, London, S.W.1. Conference enquiries should be addressed to: The Institution of Production Engineers, 10 Chesterfield Street, London, W.1.

Annual General Meeting, 10th May 1956

Notice is hereby given that the Annual General Meeting of the Royal Aeronautical Society, with which is incorporated the Institution of Aeronautical Engineers, will be held on Thursday, 10th May at 5.30 p.m. in the offices of the Society, 4 Hamilton Place, London, W.1.

Agenda

1. To read the Notice convening the Meeting.
2. To receive and deliberate upon the Report of the Council on the state of the Society and the Balance Sheets and Income and Expenditure Accounts of The Royal Aeronautical Society and Aeronautical Trusts Limited for the year ended 31st December 1955.
3. To receive the names of those elected to Council for the years 1956-1959.
4. To announce the names of Fellows elected by the Council in accordance with By-Law 4.
5. To elect the Auditors for the year 1956.
6. Any other business.

By Order of the Council

A. M. BALLANTYNE,

Secretary.

NOTE:—In accordance with the By-Laws any member whose subscription has not been paid before the first day of April is not entitled to vote.

Light refreshments will be served after the meeting.

British Commonwealth Welding Conference

The Institute of Welding invites all those in the British Commonwealth who are interested in welding processes and their applications to attend The First British Commonwealth Welding Conference to be held in London and Saltburn-by-Sea, Yorkshire, from 17th to 29th June 1957. Papers for the Conference are invited and must be submitted by 1st August 1956. Delegates will have an opportunity during the Conference to see the most advanced welding techniques used in British factories. The draft programme and enrolment form will be distributed at the end of October 1956. Copies of these and any other information may be obtained from The Secretary, Institute of Welding (C.W.C.), 2 Buckingham Palace Gardens, London, S.W.1.

Society for Experimental Stress Analysis

The Spring Meeting of the Society for Experimental Stress Analysis will be held from 16th-18th May 1956 at the William Penn Hotel, Pittsburgh, Pennsylvania. Further information may be obtained from Dr. W. M. Murray, Secretary-Treasurer, Society for Experimental Stress Analysis, P.O. Box 168, Cambridge 38, Massachusetts.

Handbook Wanted

The Society is anxious to acquire a handbook of the R.A.F.4A engine (c.1915). If any member knows of one for disposal the Librarian will be glad to hear of it.

DIARY

LONDON

12th April

SECTION DISCUSSION.—Aircraft Interior Layout. Speakers will be:—Capt. O. P. Jones, R. C. Morgan, C. F. Holloway, D. P. Thorne and a B.O.A.C. Stewardess. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

17th April

SECTION LECTURE.—Investigation of Aircraft Accidents. E. L. Ripley, O.B.E. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

19th April

MAIN LECTURE.—**High Speed Experimental Test Flying. Lt.-Col. Charles E. Yeager, U.S.A.F. The Institution of Civil Engineers, Gt. George Street, London, S.W.1. 6 p.m. (Tea 5.30 p.m.).**

24th April

SECTION LECTURE.—The Development of Helicopter Transport: Experiences Obtained in B.E.A. Experimental Flying and Operations. R. H. Whitby. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

9th May

ALL-DAY SECTION DISCUSSION ON SUPERSONIC FLIGHT.—Propulsion: A. V. Cleaver. Aerodynamics: P. J. Duncton. Structures: D. J. Farrar. Cabin Conditions, Controls, etc.: H. H. Gardner. The Institution of Civil Engineers, Gt. George Street, London, S.W.1. 10 a.m. (*See* separate Notice).

15th May

SECTION LECTURE.—Medical Aspects of Flight Comfort and Efficiency. Dr. A. Buchanan Barbour, O.B.E. The Library, 4 Hamilton Place, London, W.1. 7 p.m.

17th May

THE 44TH WILBUR WRIGHT LECTURE.—Sir William S. Farren, C.B., M.B.E. The Royal Institution, Albemarle Street, London, W.1. 6 p.m. (Tea 5.30 p.m.).

GRADUATES' AND STUDENTS' SECTION

18th April

Gas Turbines—Propeller or Jet? R. M. Fitzgerald. The Library, 4 Hamilton Place, London, W.1. 7.30 p.m.

19th May

Visit to United States Third Air Force at R.A.F., Manston.

BRANCHES

10th April

Boscombe Down.—Postponed until 24th April. Some Developments in Turbine Engines. Dr. S. G. Hooker, O.B.E.

Bristol.—Titanium—A Survey. Major P. L. Teed. Conference Room, Filton House, Bristol Aircraft Ltd. 6 p.m.

11th April

Glasgow.—Film and Annual General Meeting. St. Enoch Hotel, Glasgow. 7.15 p.m.

13th April

Birmingham.—Prop-Jets in the Navy. W. H. Lindsey. Birmingham Engineering Centre, Stephenson Place. 7.30 p.m.

14th April

Southampton.—Annual Dance. The Refectory, University of Southampton. 8-12 p.m.

16th April

Halton.—Brains Trust on High Altitude Survival. Branch Hut, R.A.F., Halton. 6.45 p.m.

18th April

Coventry.—Annual General Meeting and Films. The Wine Lodge, Coventry. 7.30 p.m.

Preston.—Annual General Meeting and Film Show. R.A.F. Association, Preston. 7.30 p.m.

Southampton.—Full-Scale Layout. J. W. Earle (Joint Meeting with the Institute of Production Engineers, Southern Section). Institute of Education, University of Southampton. 7 p.m.

19th April

Cheltenham.—Annual General Meeting and Film "We Saw it Happen." St. Mary's College, Cheltenham. 7.30 p.m.

Reading and District.—Annual General Meeting and Film Show. G. R. Volkert. Western Manufacturing Ltd. Canteen, Reading. 6 p.m.

23rd April

Halton.—Film: From Touchdown to Take-off. Branch Hut, R.A.F., Halton. 6.45 p.m.

24th April

Belfast.—Annual General Meeting. Reception Room, Kensington Hotel, Belfast. 7 p.m.

Boscombe Down.—Some Developments in Turbine Engines. Dr. S. G. Hooker, O.B.E. Lecture Hall, A. & A.E.E., Boscombe Down, Amesbury, Wilts. 5.45 p.m.

26th April

Bristol—Annual General Meeting and Film Show. Conference Room, Filton House, Bristol Aircraft Ltd. 6 p.m.

30th April

Halton.—Paper by a Junior Member. Branch Hut, R.A.F., Halton. 6.45 p.m.

2nd May

Coventry.—Visit to Duston Works of British Timken Ltd. Coach leaves Parkside at 5.35 p.m., calling at Whitley and Baginton.

7th May

Halton.—Ejection Seats, The First Decade. Wg. Cdr. J. Jewell, O.B.E. Branch Hut, R.A.F., Halton. 6.45 p.m.

9th May

Weybridge.—Annual General Meeting. Vickers-Armstrongs (Aircraft) Ltd., Weybridge. 6 p.m.

11th May

Birmingham.—Radar and Kindred Pilot Aids. The Birmingham Engineering Centre, Stephenson Place. 7.30 p.m.

14th May

Halton.—Film. Branch Hut, R.A.F., Halton. 6.45 p.m.

16th May

Glasgow.—Soaring Flight. A. H. Yates. Royal Technical College, Glasgow. 7.15 p.m.

28th May

Halton.—Film. Branch Hut, R.A.F., Halton. 6.45 p.m.

INCOME TAX

In response to enquiries from members with regard to a rebate on Income Tax for their subscriptions, the following is a copy of a letter received from the Principal Inspector of Taxes.

Ref: H.R.S.54/C.I. 4420/63.

14th August 1928.

Dear Sir,

Further to your interview with Mr. Stoneley at this office on the 19th July I am now in a position to inform you that the Board of Inland Revenue will not raise objection to the allowance as an expense for Income Tax purposes of annual subscriptions paid by members who are

(i) assessable under Schedule D of the Income Tax Acts in respect of professional or trading profits, subject to the decision of the Commissioners who make the assessment that such subscriptions are sufficiently closely related to the business carried on, or

(ii) assessable under Schedule E in those cases only in which continued membership of the Society is an essential condition of the terms of appointment.

Yours faithfully,

Signed: GEO. WILCOCK,

Principal Inspector of Taxes.

Secretary,
Royal Aeronautical Society.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Sheikh Mukarram Ali (*from Graduate*)
Peter Joseph Angus (*from Graduate*)
Ronald Henry Bell
Donald Biltcliffe
Robert Alexander Ross Black (*from Graduate*)
Philip Charles Bolt
Gordon Francis Gartshore Brown (*from Associate*)
Leslie Byram (*from Graduate*)
Jacob Alexander Bruce Cartmel (*from Graduate*)
Dennis Stratton Carton (*from Associate*)
Henry Iliffe Cozens
Gilbert Seymour Cranwell (*from Graduate*)
Eric John Davis
Antony George Dixon (*from Graduate*)
Peter John Farmer (*from Graduate*)
Ronald Charles Harris (*from Graduate*)
Cecil Charles Head (*from Associate*)
Donald Malcolm Heughan (*from Graduate*)
Paul Alexander Hilton (*from Graduate*)
Frank Stanley Houghton
Gavin Stuart Kermack (*from Graduate*)
Arthur George Kurn (*from Graduate*)
Ernest Fintan Lawlor (*from Graduate*)
Hubert Charles Beverley Mackey (*from Associate*)
Eric Cyril Maskell (*from Graduate*)
Richard Ernst Meyer
Harry Frederick Charles Newby
William Michael Geoffrey Owen (*from Graduate*)
John Gordon Hedley Pearce (*from Graduate*)
Forbes George de Brie Perry (*from Graduate*)
Ivor Leslie Kerr Rye (*from Graduate*)
Ralph Thomas Sage (*from Companion*)
Walter Richard Shapey (*from Graduate*)
Brian Worsley Bolton Shaw (*from Graduate*)
John Speechley (*from Graduate*)
Richard Fred Spinks
Patrick Edward Aston Talbot
Tudor William Thomas (*from Graduate*)
Anthony Roy Turley (*from Graduate*)
James Henry Wilson (*from Graduate*)
Macdonell Watkyn Woods

Associates

Geoffrey Thomas Beauchamp
Francis Philip Bousfield
Terence Theodore Cannon
William Kean Dunlop
Clive Ernest Fenton
George Milton Kelly
Shadi Lal (*from Student*)
Henry Maddock
Arthur William Frederick Metz
Cyril William Pearson
Arye Rottem
Walter Edward Withers
Harry Francis Young

Graduates

Howard Godfrey Allen
Maurice John Averay
Barun Chandra Basu (*from Student*)
Keith William Bateman
Derek Baxter
John Percy Bond
Alan Denham Boothroyd
Roland Victor Clark
Peter Neville Cornall (*from Student*)
John Dunham
Michael Missenden Freestone
Alan William Furneaux
Gwilym David Griffiths
Robert Donald Harman (*from Student*)
Gerald Harrison (*from Student*)
Christopher John Hawkins (*from Student*)
Paul Hollenberg (*from Student*)
Ronald Sidney Hubbard
David Malcolm Hunter
Ernest Huntley
Michael Richard Henry Jeffries (*from Student*)
Peter Robert Jempson (*from Student*)
Chuen Li (*from Student*)
John Michael McDermott (*from Student*)
Brian Angus Fleming McLellan (*from Student*)
Donald George Merchant (*from Student*)
Ronald Douglas Milne
Michael Stafford Rhodes
Ivor Ewart Scarlett
Derek Edward Shepherd
Norman Hugh Simmonds (*from Student*)
Sheikh Siraj
Anthony Taylor Smith
Christopher John Smith
John Snell
Clive Eccleston Turner
David Charles Turner
Keith Walker
Brian Scott Ward (*from Student*)
Roy George Williams

Students

Harry Samuel Bluston
Harold George Carrington
David Harold Chester
Bernard Childs
James Jack Duncan
George Roger Dunn
Peter Barry Earnshaw
Ronald Eaton
David James Eggleton
Michael George
Arthur William Norman Gordon
Arthur Gray
Collin Grimes
Philip Edward Hall
Neil Frederick George Harrison
Deirdre Elizabeth Holford
Michael Edward House
Reginald Hansard Jones
Geoffrey Charles Keevil
David Geoffrey Leigh
Douglas Frederick Mann
Maneshwar Chandra Mathur
Brian Millington
Ian Charles Moore
Brian John Nicholson
Robert Partridge
Richard Watson Quartermaine
Michael John Rawson
John William Read
David Creyke Reedman
Robert Howard Ridgwell
Brian Edwin Rowed
Charles David Shargool
Arthur William Smith
Thomas Neil Stevenson
John Charles Philip Stott
Charles Hugh Strachan
Charles Philip Swift
Colin Torkington
Brian Gilbert Ward
Leslie James Warren
John Francis Watson
Richard Alexander Wightman
Malcolm Daniel Wright

Companion

Stanley Edwin Tweedy

NEWS OF MEMBERS

J. A. H. BAILIE (*Graduate*), formerly a Stressman in the Design Office, Vickers-Armstrongs, is now a Stress Engineer at Lockheed Aircraft Corporation, Burbank, California.

F. N. R. BALLAM (*Associate*) has been appointed Electronics Engineer at Westland Aircraft Ltd.

A. S. HENNEY (*Associate Fellow*), formerly with Vickers-Armstrongs (Aircraft) Ltd., is now with Convair at San Diego as a Senior Design Engineer.

F. G. C. HENWOOD (*Associate*), formerly in New Zealand, has now taken an appointment with F. G. Miles Ltd., Shoreham Airport, Shoreham-by-Sea, West Sussex.

DR. NICHOLAS J. HOFF (*Fellow*), following a lecture tour, was presented with the University of Liege Medal.

L. R. I'ANSON (*Associate Fellow*), previously with Rolls-Royce Ltd., has joined The English Electric Company at Warton as Project Engineer.

C. E. P. JACKSON (*Associate Fellow*) has been appointed Vibration Engineer at Westland Ltd.

S. KUGLER (*Associate Fellow*), formerly Senior Development Engineer with British Oxygen Engineering Ltd., is now Senior Project Engineer at their Aircraft Equipment Development Group.

ERIC LUMLEY (*Associate*), formerly Design Draughtsman at the College of Aeronautics, Cranfield, is now Assistant Lecturer in Mechanical and Aeronautical Engineering at Newton Heath Technical College, Manchester.

A. LUMSDEN (*Associate*) has joined the Staff of the Royal Aeronautical Society and is looking after the Membership of the Society.

G. F. MILLER (*Associate*) has now joined G. J. J. Miller Automatic Screw Machine Products as Works Manager.

R. NIVET (*Associate Fellow*), formerly Chief Engineer in charge Operations Engineering Development with Air France, is now Assistant to Deputy Director General (Technical).

P. R. OWEN (*Associate Fellow*) is now Professor of The Mechanics of Fluids and Director of the Laboratory at the University of Manchester.

W. H. PAINE (*Associate Fellow*) has been appointed Assistant Engineering Manager at Westland Aircraft Ltd.

J. G. ROXBURGH (*Associate Fellow*) has been appointed Chief Planning and Progress Engineer at Handley Page Ltd.

N. P. SHEVLOFF (*Associate Fellow*) has left Short

Brothers and Harland Ltd. where he was employed as a Principal Stressman (in charge Flutter and Dynamics) and has now taken up a post as Design Specialist in Dynamics with Canadair Ltd., Montreal.

PROFESSOR A. V. STEPHENS (*Fellow*) has been appointed first holder of the New Chair of Aeronautical Engineering at Queen's University, Belfast.

J. W. WILSON (*Associate*) has left British Messier Ltd., Gloucester, and has taken up a position as Project Engineer with Messrs. Integral Ltd., Wolverhampton.

THE CANTOR LECTURES

The Three Cantor Lectures, on "Modern Welding," will be given by Dr. H. G. Taylor on 16th, 23rd and 30th April at the Royal Society of Arts, John Adam Street, Adelphi, W.C.2.

ASSOCIATE FELLOWSHIP EXAMINATION RESULTS

The following candidates were successful in the Associate Fellowship Examination held in December 1955:—

PART I—LONDON

D. O. CHALLIS, Applied Mathematics, Properties of Matter, Heat, Light and Sound, Theory of Machines.

D. W. EVANS, Applied Mathematics, Properties of Matter, Heat, Light and Sound, Aerodynamics.

A. FINAZ, Applied Mathematics, Magnetism, Electricity and Electronics, Strength of Aircraft Materials and Theory of Structures, Theory of Machines.

J. R. LYON, Strength of Aircraft Materials and Theory of Structures.

A. A. MUNDAY, Strength of Aircraft Materials and Theory of Structures.

J. C. STANTON, Aerodynamics.

A. L. WEBB, Theory of Machines; D. H. WINGATE, Applied Mathematics, Strength of Aircraft Materials and Theory of Structures, Theory of Machines.

PART II—LONDON

W. B. BLYDENSTEIN, Air Transport.

M. FARMER, Navigation; C. F. FORER, Strength of Materials and Theory of Structures.

G. L. HEARNE, Strength of Materials and Theory of Structures; K. G. HODSON, Aerodynamics.

K. MCQUADE, Aircraft Design: M. E. A. MANNING, Engine Design.

V. PETSOUNIS, Strength of Materials and Theory of Structures; J. PICKARD, Strength of Materials and Theory of Structures (Awarded Baden-Powell Prize); Squadron Leader R. F. PLUCKNETT, A.R.Ae.S., Meteorology; A. P. N. POTTS, Aerodynamics.

Miss P. M. SMITH, Aerodynamics.

A. B. TAYLOR, Aircraft Design; S. M. TURNER, Aerodynamics.

E. S. F. WRIGHT, Engine Design (*See* Part I—New Syllabus).

PART I—NEW SYLLABUS

Flying Officer J. M. BRANT, Thermodynamics.

D. J. L. LEWIS, Pure Mathematics, Mechanics, Physics, Aerodynamics.

E. S. F. WRIGHT, Thermodynamics, Theory of Machines (*See* Part II—Old Syllabus).

PART I—ABROAD

TULSI DASS (Poona), Properties of Matter, Heat, Light and Sound.

TILAK RAJ (Delhi), Applied Mathematics, Magnetism, Electricity and Electronics, Aerodynamics.

J. F. TEAGUE (Adelaide), Applied Mathematics, Aerodynamics, Theory of Machines.

PART II—ABROAD

H. M. ISRAEL (Mysore), Aerodynamics.

B. N. VAMAN RAO (Mysore), Aircraft Materials.

PART I—ABROAD—NEW SYLLABUS

V. SHRIDHER HEDGE (Poona), Aerodynamics.

G. S. UPPAL (Dehli), Thermodynamics, Theory of Machines.

JOURNAL BINDING

Permanent Binding

The new prices for permanent binding of Journals are:

1955 Volume (including packing and postage) £1 0s. 0d.

Previous Volumes (including packing and postage) .. .. £1 1s. 6d.

Journals, with a note of the name and address of the sender, should be sent direct to The Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the Offices of the Society.

Self-Binder Cases

Self-Binder cases of the "Easibind" type to hold 12 Journals (cost 11s. 6d. each) are available from the offices of the Society.

CHANGES OF ADDRESS OR APPOINTMENT

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address. He would also like to know of any change of appointment.

When notifying changes please give the following particulars:—

Name (in block letters). New address (in block letters).

Grade of Membership. Old address.

New appointment—Please give name and address of employer and position held.

Changes of address must be received *before the 15th of the month* in order to be effective for the JOURNAL for the following month.

The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 60 APRIL 1956 NUMBER 544

A Review of Some Combustion Problems Associated with the Aero Gas Turbine

by

J. S. CLARKE, O.B.E., Ph.D. M.I.Mech.E., F.R.Ae.S.

(Chief Research Engineer and Technical Director, Burnley Research Laboratories, Joseph Lucas (Gas Turbine Equipment) Ltd.)

The 23rd Main Lecture to be given before a Branch of the Society was held under the auspices of the Merthyr Tydfil Branch on 10th November 1955. The Lecture, entitled "A Review of Some Combustion Problems Associated with the Aero Gas Turbine," was given by Dr. J. S. Clarke, O.B.E., M.I.Mech.E., F.R.Ae.S. Mr. C. S. Gardner, Past President of the Merthyr Tydfil Branch, opened the proceedings by welcoming the guests. He was deputising for Mr. W. R. Morgan, the Branch President, who had unfortunately had to go into a nursing home for treatment for an old war injury. He apologised also for the absence of Mr. McGibbon who arrived back from America only that day and was unable to be present. He then introduced Mr. N. E. Rowe, President of the Royal Aeronautical Society, whom they were very honoured indeed to have with them. When they thought of the journeyings that his presence involved he thought they should be all the more grateful that he could come and support them in their Branch. He would ask Mr. Rowe to take the Chair.

MR. N. E. ROWE, C.B.E., B.Sc., F.C.G.I., F.I.A.S., F.R.Ae.S.:—This was a Main Lecture of the Royal Aeronautical Society, which was why he had the privilege of taking the meeting. He was delighted to be there because he believed that the work of the Branches was extremely important.

The Lecturer, Dr. Clarke, was educated at Birmingham University, where he was a James Watt Fellow. He was a Compton Medallist of the Institution of Automobile Engineers and held the Vickers Gold Medal and Prize of the Junior Institute of Engineers. He was with the Industrial Research Laboratories of the City of Birmingham Gas Department for ten years from 1931 and since 1941 he had been Director of the Combustion and Research Laboratories of Joseph Lucas Ltd., Burnley, where, if any one had visited it, they would have seen the tremendous work of research and development that went on and the very great advances that had been made in this particular field of combustion on which Dr. Clarke was to speak.

Introduction

It is not without interest that the Institution of Mechanical Engineers have held a Joint Conference on Combustion with the American Society of Engineers[1] and numerous other conferences have taken place on the subject during the past few years. It is impossible in this instance to do more than draw attention to the fact that a great deal of fundamental flame work has been done in this country and elsewhere during this time.

Although engineers dealing with combustion largely associate the phenomenon of flame with aerodynamics, there is the chemical aspect which must always receive attention and study, particularly if an appreciation of the ultimate heat release which may be expected under prescribed conditions is to be attained. Some of the chemical factors are dealt with by Egerton, Saunders and Spalding[2], Lewis and von Elbe[3], and Longwell and Weiss[4].

Referring to Egerton's work[2], an interesting observation has been made, namely the selective oxidation of methane in the presence of carbon monoxide. This may have important effects on the design of combustion chambers from the point of view of combustion efficiency, heat release and minimum length.

The present paper has been written in the light of experiences and detailed studies of the burning of atomised sprays. It will be appreciated that this is because of the tremendous integrated experience built up in the Laboratories over the years by virtue of the continuous application of this particular system.

1. Operating Conditions of an Aircraft Combustion Chamber

One of the special requirements of an aircraft gas turbine combustion chamber is its ability to work satisfactorily over a wide range of throughput conditions. This range involves the air inlet pressure and temperature and the air and fuel mass flow rates, and arises from the varying atmospheric conditions at different altitudes and the varying degree of compression due to aircraft speed and engine rotational speed.

Since aircraft performance is increasing, both as regards altitude and Flight Mach number, the range to

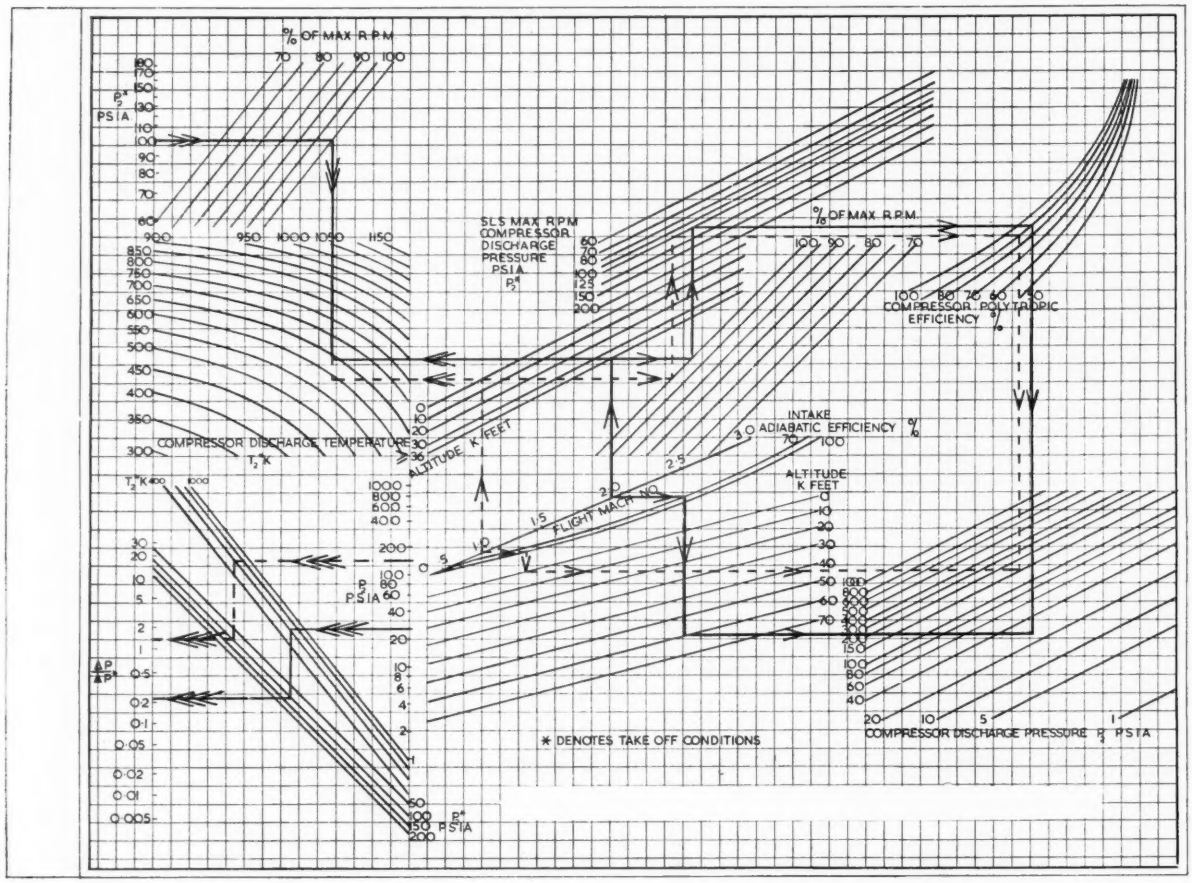

FIGURE 1. Nomogram for finding air pressure and temperature and pressure drop in an aero gas turbine combustion chamber.

be covered in terms of combustion chamber performance is ever widening.

The air pressure and temperature in the chamber depend not only on the altitude and flight Mach number, but also on the efficiencies of the intake and the compressor and on the compressor speed and nominal compression ratio. The manner of this dependence is shown in nomogrammic form in Fig. 1.

This chart enables not only the combustion pressure and temperature at any arbitrary conditions to be determined by a graphical method, but also the ratio in which any pressure loss in the chamber is affected. The dotted line shows an example of the use of this nomogram for the case of a flight Mach number of 1.0 at sea level at full engine r.p.m. giving a compressor delivery pressure of about 150 p.s.i.a., as against 100 p.s.i.a. at the take-off condition. The full line shows a corresponding example at a flight Mach number of 2.0 at 60,000 ft. In other cases the attainment of high flight Mach numbers may double or even treble the pressure loss across, say, a flame tube. This is a factor which must be remembered when stressing the structure at the design stage.

Figures 2 and 3 show a selection of the results which may be obtained from this chart. Fig. 2 shows the combustion chamber pressure at full rotational speed, and illustrates how severely the pressure can be reduced by flight at a high altitude, and how this may be recovered to some extent by the use of a high flight Mach number. At the low altitudes, it is also seen that high aircraft speeds can increase the combustion chamber pressure very greatly, a fact which must be borne in mind when designing the strength of the outer casing.

The corresponding data on combustion chamber air inlet temperature at full rotational speed is given in Fig. 3 from which the most outstanding feature is the high temperature which may arise in the case of high flight Mach number. A Mach number of 2 for example, will give an air temperature some 230°C higher at sea level than the corresponding temperature without ram.

Not only do these high air temperatures cause special difficulties to arise in flame tube cooling and other combustion chamber design matters, but they also lead the engine designer to consider the possibility of raising the turbine inlet temperature. In an extreme case, this is the only possible way of maintaining the cycle efficiency.

This rise in designed turbine inlet temperatures raises two separate groups of problems. The problems of turbine blade cooling which allow high gas temperature to be used without damage to the blades are under active study elsewhere. The problems of combustion chamber design arise from the increased heat release rate required, together with the unusually small quantity of dilution air relative to primary air.

The high flight Mach numbers which are demanded in certain aircraft nowadays introduce further combustion problems. Aircraft drag assumes increased importance, and installed engine diameter for a given thrust has to be reduced to a minimum. In different types of engine design the greatest diameter may be the intake, the compressor, the combustion chamber, the turbine, the reheat system or the final nozzle. The cases in which the compressor, the combustion chamber or the turbine has the greatest diameter have led to continual improvements in the design of these items, and it is now possible to design "constant diameter engines" in which all these items are built into a common cylindrical shell.

This trend has led to progressive increases in "full section" velocity and Mach number in the combustion chamber. By this is meant the velocity or Mach number calculated from the air mass flow, the air temperature and pressure at inlet to the combustion chamber and the maximum cross-sectional area of flow path in the combustion chamber.

With the current design standard of compressor and turbine, and when using a fully annular combustion chamber on a more or less constant diameter engine, this full section Mach number may nowadays have to be up to 50 per cent. or even 100 per cent. greater than the values usual in the past.

2. Flame Stabilisation and Heat Release Rate

To secure flame stabilisation, it is necessary in general to pay attention to three separate factors; inflammability of the mixture, flame speed, and the geometry of the stabiliser in relation to the flow of air and combustible past it.

Mixture inflammability curves showing the range of mixture strengths over which combustion is possible at various absolute pressures always show a range which is centred more or less upon the stoichiometric mixture, and at this optimum strength, the minimum pressure at which combustion will occur under closed vessel conditions at room temperature is of the order of 0.1 to 0.3 p.s.i.a.

The type of combustion in question at the moment

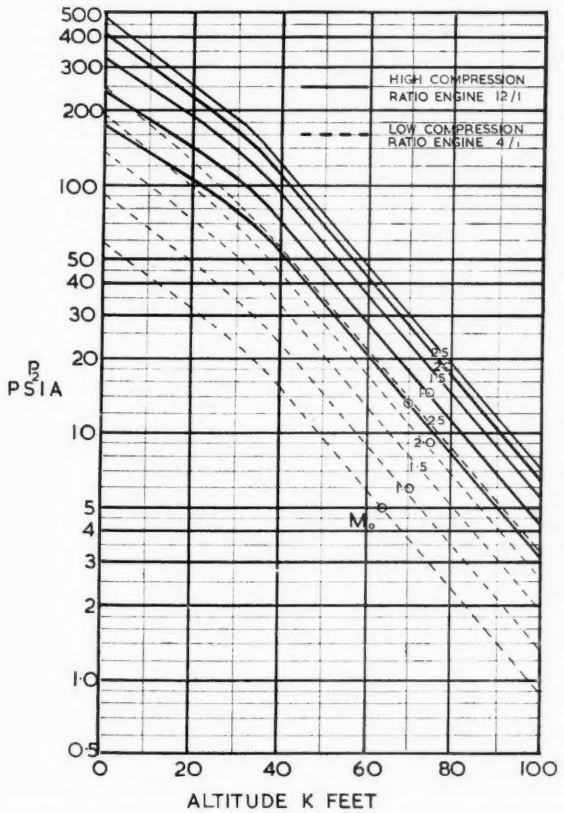

FIGURE 2. Combustion chamber pressure plotted against altitude, flight Mach number and compression ratio.

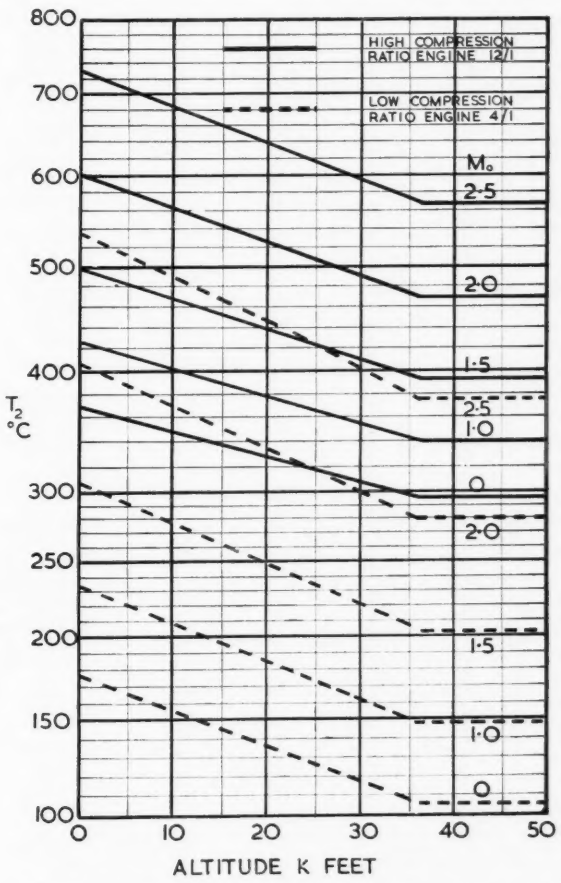

FIGURE 3. Combustion inlet temperature plotted against altitude, flight Mach number and compression ratio.

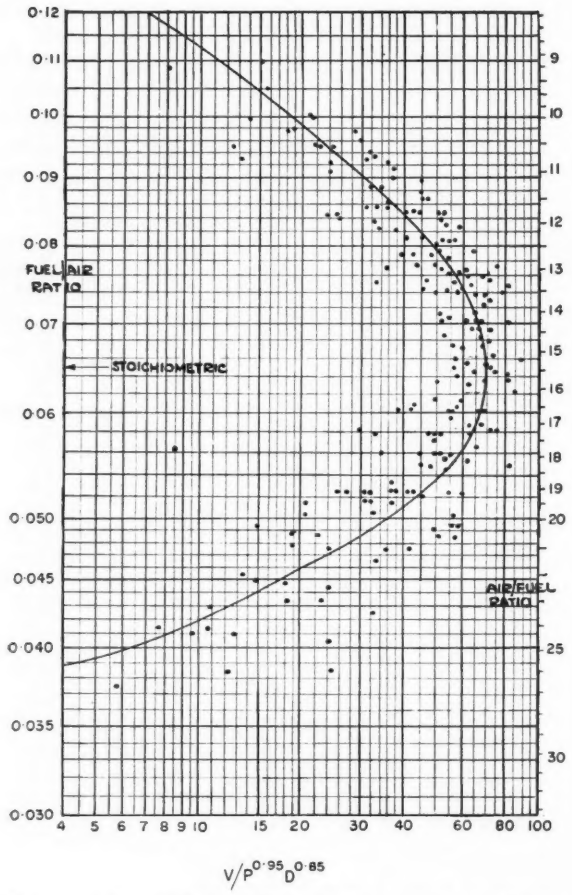

FIGURE 4. Combustion stability loop for propane-air mixture.

is that in which the flame is piloted by a recirculation of combustion products, and in which the combustibles are more or less vitiated by inert products at the moment of inflammation. This has a deleterious effect upon the limits of inflammability. For example a gasoline-air mixture whose limits are from half to two times the stoichiometric ratio at half an atmosphere has this range steadily narrowed down to nothing by the progressive addition of CO_2 up to 30 per cent.

Passing to the question of flame speeds, these also have an optimum in the neighbourhood of stoichiometric mixture. The laminar speeds, which are the most convenient to measure are very low compared with the air velocities encountered in aero practice. One to 2 ft./sec. is a common maximum value.

However, it is nearly always the turbulent conditions that apply, and under these circumstances the flame velocity is several times greater than in the laminar case. Even so it is still low enough to make the successful achievement of a stabilising system strongly dependent upon the provision of a well-designed baffle with a sheltered wake or interior.

The simplest form of baffle is the circular disc placed transversely and centrally in a uniform stream of premixed combustible in a circular pipe. In such a case, the gas velocity, baffle size and absolute pressure all play a part in determining the limits of mixture strength for stable combustion, and it is sometimes possible to find a function of these which may be used to plot a comprehensive stability loop.

This has been done in a particular case by De Zubay[5], who obtained the loop shown in Fig. 4 by plotting against $V/P^{0.95}\,D^{0.85}$ where V, the gas velocity, varied from 40 to 550 ft./sec., D, the disc diameter, varied from $\frac{1}{4}$ in. to 1 in. and P, the absolute pressure, varied from 3 to 15 p.s.i.a.. The gas was a propane-air mixture initially at room temperature. The combustion downstream of a flat baffle of this type is usually associated with a long flame, which is unacceptable for aircraft gas turbine applications.

The combustion problem in the aero gas turbine normally involves the burning, not of a uniform premixture, but of an atomised liquid spray injected into an air stream, or the fuel may be discharged into a vaporising tube. It is only with the case of direct liquid spray injection, however, that this paper deals. Although the combustion limits are wider in this case than with the premixture, the achievement of satisfactory combustion and stability range now depends upon a number of further factors, and chiefly upon the development of a suitable flow pattern.

The flow pattern due to a simple transverse disc is shown in Fig. 5 and its chief defect is that the only mechanism for transfer of flow into the wake is by the diffusion of turbulent eddies across the boundary stream line. This amount of transfer is inadequate for the

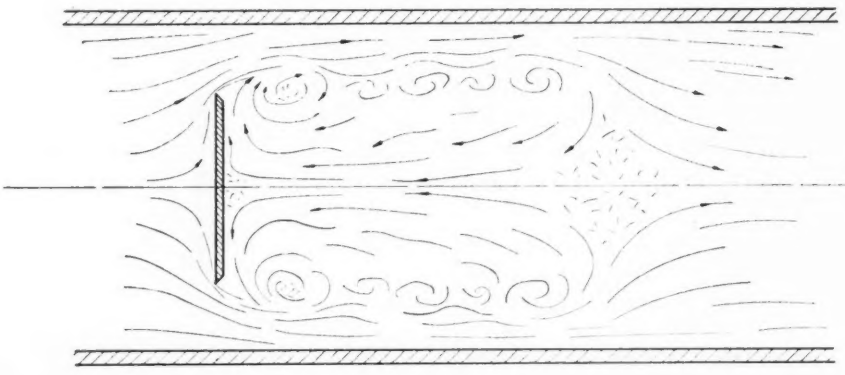

FIGURE 5. Instantaneous flow pattern caused by sharp-edged circular baffle set transversely in a circular duct.

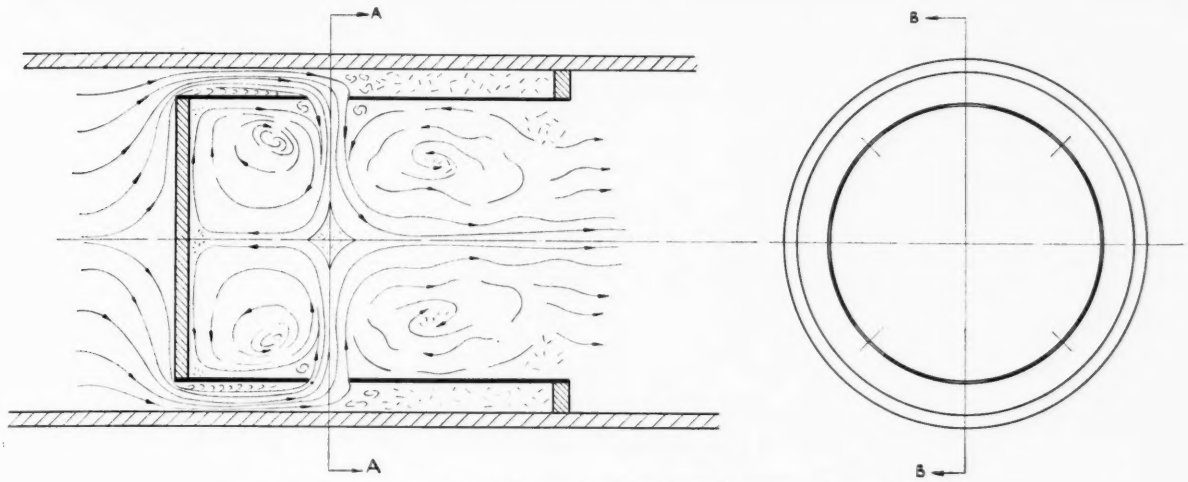

FIGURE 6. Flow pattern across diametral section through centres of opposing holes.

achievement of an efficient short flame without any other aid.

The first improvement that can be made is to attach a flame tube to the edge of the disc, and to inject the primary air through a row of holes in its perimeter. Fig. 6 shows the resulting pattern, and it will be appreciated that another mechanism is now involved in causing recirculation. The penetrating air streams collide on the centre line, and a proportion of the combined flow passes upstream to refresh the toroidal vortex and to augment its fuel burning capacity. The corresponding out flow from the vortex passes downstream in between the positions of the side air injection holes.

Because of the natural turbulence of a system of this type, and sometimes the mechanical inaccuracy or one-sided air distribution approaching the system, it is difficult to depend upon the reverse flow being accurately placed on the centre line of the tube. The addition of a primary air swirler ensures this, and at the same time imparts a small degree of axial swirl up to the primary zone. This swirler, however, must not be allowed to pass too much of the primary air flow, since it tends to create a pattern which is somewhat contradictory to the main toroidal vortex round which the system is built. Fig. 7 shows the generalised axial swirl which can arise if too large a proportion of the primary air flow is passed through the swirler.

Finally, Fig. 8 shows the complete flow pattern which results when a system developed on the lines summarised above is incorporated into the primary zone of a combustion chamber.

In chambers designed along these lines, very high specific rates of heat release can be obtained in terms of millions of C.H.U./(ft.^{2} hr. atm.). Over 5 millions can be obtained in an aero gas turbine chamber running at the full load condition, given an adequate allowance of pressure loss, and this is still with a fractional pressure

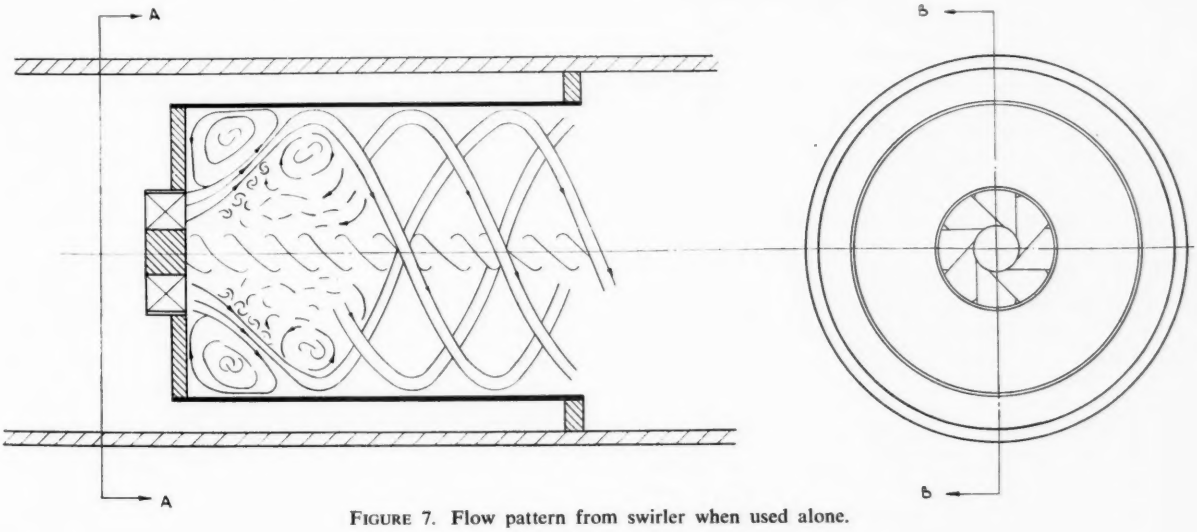

FIGURE 7. Flow pattern from swirler when used alone.

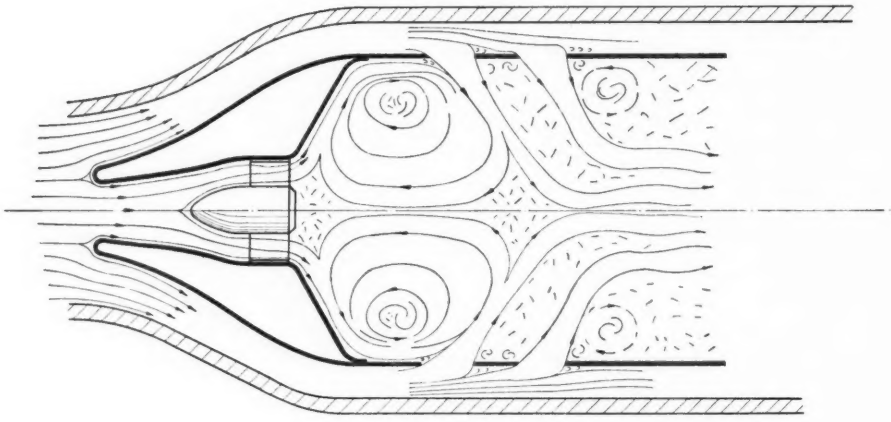

FIGURE 8. Flow pattern in primary zone with suitable approach ducting.

loss which does not damage the cycle efficiency unduly.

Experiments have been carried out in recent years to determine the highest attainable combustion intensities, limited only by considerations of chemical kinetics. In recent work by Longwell and Weiss[6], this has been done by using a spherical combustion chamber with radially outward flow from the surface of a smaller concentric sphere. They give their space heat release rates on the basis of heat units per cubic foot per hour per atmosphere$^{1\cdot8}$ and quote a value for the limiting rate of about 170×10^6 C.H.U./(ft.^{3} atm.$^{1\cdot8}$) for stoichiometric mixtures.

Their results show, however, that this rate is reduced considerably for weaker mixtures and also when heat losses from the flame occur. For example, when operating at a weaker mixture of equivalence ratio 0.5, the limiting heat release falls to about $5{\cdot}5 \times 10^6$ C.H.U./(ft.^{3} hr. atm.$^{1\cdot8}$) while a heat loss of 5 per cent. reduces the maximum rate by more than 30 per cent.

In a practical combustion chamber we have both non-stoichiometric conditions and heat losses in the primary zone. Thus on making allowances for these factors it would appear that the achievement of some rate approaching a limiting value is not as formidable a task as it might seem at first sight.

These results of course do underline the importance of operating as near to stoichiometric mixture strength in the primary zone as possible and of minimising heat losses.

3. Comparison of Pipe, Tubo and Fully Annular Chambers and Upstream and Downstream Fuel Injection

The three main types of combustion chamber are illustrated diagrammatically in Fig. 9 for purposes of comparison.

The upper diagram shows part of a ring of pipe chambers such as is used on many of the earlier aero gas turbine engines, and on several even today. The compressor discharge is split into a number of separate sectors, depending on the number of chambers chosen, and the flow through each is ducted into a transition section leading to the circular casing. The casing contains a flame tube into which, ultimately, all the flow passes, and is finally led through a further transition section to a sector representing the appropriate fraction of the turbine inlet annulus.

One of the most outstanding advantages of this system is the fact that the combustion chamber unit is a relatively small piece of equipment which does not offer in general, such severe design problems as the annular types, and which can be cheaply manufactured, tested, developed, serviced, or replaced.

On the other hand, the provision of sector to circular transition pieces at both ends of the chamber necessitates extra length and awkwardly shaped components. The inlet transition piece, in particular, hinders the diffuser design and imposes parasitic pressure losses in the air stream. Maldistribution of flow at the outlet from this transition piece may upset the combustion process or necessitate the use of a higher pressure drop for this than would otherwise be necessary.

Perhaps the most serious disadvantage of the pipe chamber layout, however, is the inefficiency of utilisation of the cross section available for the combustion equipment. The upper diagram on Fig. 9 shows a typical arrangement in which the ratio of outermost to innermost diameter of the allotted space is 2 to 1 while a reasonable clearance has been allowed between successive pipe chambers. As a result, the total cross section of the casing is only 67 per cent. of the space allotted in this particular case.

As mentioned in Section 1, there are many engines in which overall diameter has to be minimised and in which such a poor efficiency of space utilisation is intolerable. This efficiency can be stepped straight up to 100 per cent. by passing to the annular chamber designs.

The tubo-annular type is illustrated in the middle diagram on Fig. 9 and seems, at a first glance, to overcome many of the disadvantages enumerated above for the pipe chamber. The total perimeter of inner and outer casings is less than that of the equivalent set of pipe chambers, but this does not in general lead to an

economy of weight since the greater diameter at a given gauge pressure will require an increased thickness.

The diffuser design is apparently facilitated, and, as far as the outer casing is concerned, there are no transition pieces to be provided at either end of the chamber. In reality, however, it must be realised that the secondary and dilution air are being called upon to transform from a fully annular cross section at the compressor discharge to an irregular shape at the maximum plane, consisting of the inner and outer "triangular" gaps between the successive flame tubes. Although this does not necessitate the provision of components of an awkward shape, it is prone to impose parasitic pressure losses, poor diffusion efficiency and flow maldistribution upon the system.

At discharge from the flame tube the complementary problem exists, and there are two usual solutions. In the simplest arrangement the flame tube tails are circular, and discharge into transition ducts which transform to the appropriate sector shape at the turbine entry itself. In the other method, part of this necessary shape change is undertaken before the flame tube tail is reached. Its shape therefore lies intermediate between a circle and a sector, and the remaining transition section need not be so long.

The tubo-annular arrangement has part of the production advantage of the pipe chamber in that the tooling, testing, development and servicing of the flame tubes is relatively easy, although the casing design may be troublesome to ensure easy access to the flame tubes.

A disadvantage of the tubo-annular layout concerns the ratio of flame tube to casing cross-sectional area. In the initial design process, certain criteria are adopted which lead to a choice of this ratio, and it so happens that the required ratio can often be realised by a reasonable choice of the number and spacing of the tubes. In the middle diagram on Fig. 9 this ratio is 56 per cent.

However on occasion, a higher ratio is desirable, and this cannot be obtained by any practicable increase in the flame tube sizes, and a design compromise becomes necessary. With the adoption of higher turbine inlet temperatures, as foreshadowed in Section 1, and with the introduction of special devices to allow high air velocities in the space surrounding the tubes to be used without detriment to the pressure loss of the chamber, it will often be found that the most desirable ratio of flame tube to casing cross-sectional area is very much higher than the figure of 56 per cent. given, and that it is quite impracticable to approach it except by abandoning the tubo-annular design conception in favour of a fully annular design of chamber.

The lower diagram on Fig. 9 shows such a design, and it is immediately apparent that there is 100 per cent. utilisation of allotted space, together with complete freedom of choice of ratio of flame tube to casing cross-sectional areas. Moreover, there is no need for transition pieces at the front or the rear since the flow is of fully annular shape throughout.

The tooling cost will be much raised because of the relatively great size of the flame tube and flame tube

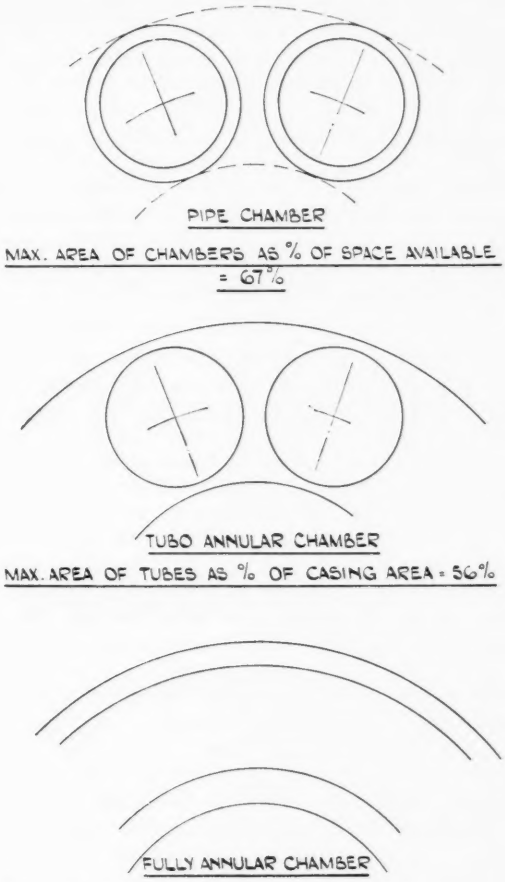
PIPE CHAMBER
MAX. AREA OF CHAMBERS AS % OF SPACE AVAILABLE = 67%
TUBO ANNULAR CHAMBER
MAX. AREA OF TUBES AS % OF CASING AREA = 56%
FULLY ANNULAR CHAMBER

FIGURE 9. Comparison of pipe, tubo and fully annular principles.

head members. Development work will be difficult and lengthy and testing, servicing and replacement of flame tubes will be expensive. Besides this, stress problems on the flame tubes will be of greater severity due to the increased size.

Another group of problems arises on this design from the fact that the flame space no longer consists of a group of small cylinders, but still receives its fuel (in the cases discussed in the present paper) from a group of swirl atomisers. This necessitates a fresh approach to primary flow pattern design.

With regard to the relationship between the spray and the primary air flow pattern, it would appear from existing experience, that one of the best arrangements is the conventional swirler and flare combination with a swirl atomiser situated co-axially with the air swirler. In this way, the initial direction of the fuel droplets is perpendicular to the air flow stream lines of the local toroidal vortex, and a beneficial shearing action is obtained. This principle applies both to upstream and downstream fuel injection systems, but in the upstream case, the droplets have a longer trajectory in the hot primary zone, and give therefore a better performance in

terms of combustion efficiency, especially at weak mixtures.

The upstream injection system also overcomes some of the disadvantages due to the stem of the downstream sprayer which is inclined to throw a shadow through the air swirler, or to create an additional parasitic loss in the expansion chamber annulus and a low velocity wake associated with local flame tube over-heating. The accommodation of the upstream injection sprayer generally presents also an easier design problem.

4. Combustion Problems

4.1. TEMPERATURE TRAVERSE

The importance of securing the required distribution of temperature into the turbine has been pointed out already. The radial temperature gradient must be adjusted to suit the stress distribution in the rotor blades. The more accurately this is done, the higher the mean temperature which may be used safely at the turbine inlet. This factor becomes more important progressively as the turbine inlet temperature is raised.

The temperature distribution arises from the degree of mixing of the dilution air with the products of primary combustion, and the most obvious way of tackling the problem is to aim at a uniform flow of primary zone products at a uniform temperature, and then develop a means of injecting dilution air to secure the required mixing of the two streams.

This is not, however, the traditional way in which the problem has been tackled so far because it calls for a tremendous amount of fundamental research work.

The important point is that the dilution flow and the primary flow should be matched to one another, and the search for such a matched system has been the target of most of the dilution development work which has been done since the early years of the last decade.

By accepting the primary combustion product distribution as it is discharged from the primary zone of a conventional chamber, and without determining this distribution in detail, it has been possible to apply judicious " cut and try " methods of dilution air injection to good purpose, and in many cases, very good final turbine entry temperature distributions have been achieved without a complete understanding of the mechanism involved.

To take any major step forward from this point, it is obviously necessary to go back to some extent over the ground which has been covered, and to obtain by patient experiment a fuller appreciation of the mechanism of the mixing.

With flame tubes of the pipe or tubo-annular type, experience has shown that good results are obtained from a dilution system consisting basically of four relatively large holes. The geometrical peculiarities of a given chamber often make necessary final adjustments to the dilution system in the course of development, as for instance by adjusting the position or by adding trimming holes.

With flame tubes of the fully annular type, on the other hand, although the same general principle of relatively few and large holes is applicable, there are obviously more degrees of freedom to choose from; for example, the ratio of inner to outer dilution air, and the axial or circumferential relative position of the inner and outer holes. It might therefore be expected that a good system would be found more readily, but as against this it must be remembered that the construction, testing and development of ideas of this sort are very lengthy and expensive processes.

When comparing the temperature traverses of pipe chambers and annular chambers, it must be remembered that a full set of pipe chambers, as used on an engine, will have an element of variability due to unequal sharing of the air and fuel, and that the final peak temperature from the set will therefore exceed, in general, that from any one tube when tested separately.

4.2. PRESSURE LOSS

The pressure loss in a combustion chamber is of three main types, the parasitic, combustion and mixing loss. Of these, the combustion and mixing loss are largely in parallel with one another since the former is applied to the primary air and the latter to the dilution. To these is added the parasitic loss " in series ", and this is incurred, in the main, upstream of the primary zone.

The injurious effects of the pressure loss upon the cycle performance of the turbine are well known, and unless it is reduced to a minimum, the expansion efficiency may suffer seriously.

The means of reducing parasitic loss are largely aerodynamic in nature; the provision of smooth ducts, gentle diffusion and generous radii of bends, and the fairing off of any obstructions.

As for the combustion loss, this dictates the velocity of entry of the primary air into the flame tube, whether from the swirler or from the usual primary holes in the main flame tube wall. It therefore determines the system of recirculating velocities in the primary zone flow pattern, and the amount of mass flow in the recirculation is fixed. In general, this amount is insufficient to oxidise more than a fraction of the fuel flow, the remainder being burnt in those other parts of the primary pattern which lie, in the fully annular case, adjacent to the vortex, and in the pipe or tubo case, downstream of it.

4.3. COMBUSTION EFFICIENCY

At full load conditions, and assuming a reasonable choice of primary air/fuel ratio, combustion efficiency rarely gives any trouble. This is largely due to the intense heat in the primary zone which ensures effective evaporation of the whole of the spray at an early stage.

It is under partial loads that combustion efficiency is more difficult to maintain, and this is associated with several factors; reduced fuel flow, weaker mixtures, coarser atomisation, worsened fuel distribution, slower evaporation, less efficient oxygenation, and slower reaction. In spite of this, the operating conditions of the chamber are usually such that the residence time at partial loads is no greater, or very little greater, than at the full load.

Much can be done to avoid the disadvantages of low

fuel flow and pressure by the use of special types of fuel injector, such as the Duplex types which enable the fuel injection velocity into the primary flow pattern to be maintained at a satisfactory level, and the droplet sizes to be kept down in a range where rapid evaporation is still possible. By maintaining the atomising pressure in this way, fuel distribution problems are also avoided or mitigated to some extent.

The evaporation rate of the droplets depends on the Reynolds number of their velocity relative to the air flow, and is thus inevitably reduced as the combustion chamber pressure falls. This is an effect which cannot be avoided, and which must, if it proceeds far enough, cause breakdown of the evaporation, and flame extinction at the minimum pressure toe of the extinction loop.

Considering the paths of the droplets through the primary zone flow pattern, it will be appreciated that partial loads must inevitably cause changes in the relative distribution of air and evaporated fuel. When such changes proceed far enough, the fuel-air mixture in the primary zone becomes unbalanced, and combustion cannot be completed before the dilution zone is reached.

Comparing the upstream and downstream injection systems, however, as mentioned in Section 3, it will be appreciated that the former gives a better opportunity for the evaporation to be completed in difficult cases.

4.4. THE EFFECT OF FUEL PROPERTIES

Liquid fuels used in the gas turbine (for example, kerosine with an average formula of $C_{12}H_{24}$) consist essentially of many different hydrocarbons—each having its own physical and chemical properties.

For practical purposes, however, these hydrocarbons are generally classified into four main groups:—Paraffins, Olefines, Napthenes and Aromatics.

Broadly speaking, Paraffins are saturated open-chain compounds, Olefines are open-chain compounds with some unsaturation, Napthenes take the form of saturated rings and the Aromatics contain unsaturated ring compounds.

The effect of fuel properties upon combustion is best considered under the headings of chemical and physical characteristics respectively, although the two are interrelated.

A great deal of theoretical and experimental work has been carried out on the chemical aspect, for example, studies of spontaneous ignition, delay periods, inflammability limits and flame speeds related to chemical composition. A detailed treatment of this work is a vast undertaking and quite outside the scope of this paper. To generalise, one may say that the chemical structure of fuels is not a significant factor in gas turbine combustion except at the most arduous conditions of low pressure, low temperature and poor atomisation.

The effect of high carbon/hydrogen ratio, that is high aromatic or unsaturated content, in encouraging carbon formation is well known, but in general the difficulty may be overcome by fine atomisation and careful control of air-swept surfaces.

From the physical aspect the picture is quite different. As one might expect, ignition under low temperature and weak mixture blow-out are influenced appreciably by volatility, being favoured by high volatility—in fact, the temperature at which the first 10 per cent. of the fuel has distilled, is often used as a criterion. In passing to the upper part of the distillation curve the quantity of "heavy ends" has a bearing on combustion efficiency loss. Atomisation is, of course, of paramount importance and fuel viscosity and surface tension have a direct bearing on this process.

4.5. CARBON FORMATION

Carbon is formed when a hydrocarbon fuel is decomposed by heat in circumstances where insufficient oxygen is immediately available for the generation of CO_2 instead.

This may happen in the gaseous or the liquid phase. In the gaseous phase, a gaseous fuel or an evaporated fuel is mixed with too little oxidant, and subjected to heat by its presence in a combustion zone. Carbon is bound to be formed, and the flame is yellow, and it is only under certain conditions of temperature in the remainder of the flow pattern that this carbon may be oxidised. If it is not so oxidised, it is either deposited in the chamber or discharged as smoke, both events being undesirable from different points of view.

It is found, when running the same combustion system under different pressure conditions, that the higher pressures are usually associated with heavier degrees of carbon formation and dense flames, while under low pressure conditions, the flame is frequently bluish, and comparatively free from carbon.

In the liquid phase, carbon can be generated on a wall or in mid-stream. An accumulation of fuel on a wall may receive heat by radiation or may run on to a part already hot, and so be subjected to cracking. This should never occur, and can always be regarded as a sign of faulty design.

In mid-stream, however, it is normal for some of the larger droplets to be so heated before their evaporation is complete, that their centres crack and a carbon particle is formed, often of the cenospheric type due to nucleate boiling of the fuel. Again, the flame is yellow, and as in the case of gaseous phase carbon formation, the particle must be burnt if satisfactory combustion is to be achieved.

The problems to be overcome are therefore twofold. In the first place, the carbon must be prevented from reaching and adhering to the wall, and in the second place it must be burnt. In many existing combustion systems these problems are solved in a satisfactory way, since although the flame is yellow, no carbon makes itself evident either on the wall or in the exhaust. This is usually due to a flame structure which allows the carbon to be burnt almost immediately after its formation. Although it is possible to prevent carbon from being deposited on a wall by sufficient scouring, this nearly always results in a smoky exhaust because the carbon thus swept aside is cooled, and is almost impossible to burn.

5. Progress and Trends in Combustion Chamber Design

It will be appreciated that the Burnley Research Laboratories have been engaged on the design and development of combustion chambers for aero gas turbines ever since the development of the Whittle engine in 1941. It will be of interest therefore to review the progress made during that time.

The requirements laid down by engine manufacturers have, on the whole, become more and more exacting, and the performance obtained in certain chambers nowadays would not have been entertained as a practical possibility at the beginning of this period. For example, the provision of adequate length in the engine to accommodate the high length to diameter ratio of chamber originally required, was a serious problem, and led to the bent engine designs originally used, but rarely required today. Thus the length from atomiser to turbine was 3 to 4 times the outer casing diameter of the pipe chamber until skill was acquired in producing short efficient flames by the methods described elsewhere in this paper. Nowadays a ratio of 2 is quite sufficient for ordinary purposes.

An important figure of merit in combustion design is the fuel consumption per unit of flame tube weight. Fig. 10 shows a collection of data referring separately to pipe chambers, tubo-annular chambers and fully annular chambers, in which this figure of merit is plotted against a function composed of all the factors which would be expected theoretically to exert an influence upon it. This function is:—

$$ZD\,(P\Delta P)^{\frac{1}{2}}/(hM)$$

where Z primary air/total air (per cent.)
D hydraulic mean depth of flame tube (inch)
P inlet pressure (p.s.i.a.)
ΔP wall loss (p.s.i.)
h flame tube thickness (inch)
M casing Mach number

On the figure, a grand mean line is drawn through all the points, but in fact there has been a steady improvement in this factor over the years. Besides this there is a lot of inevitable scatter due to the individual differences between one chamber and another.

The progress made in the direction of reduced pressure loss can best be appreciated by reference to the expression known as " Pressure Loss Factor," or P.L.F., which is equal to the actual loss of total pressure divided by the kinetic head of the incoming flow based on the maximum cross section of the chamber.

Bent engines naturally show up very badly in this respect because part of the cross section of the chamber is occupied by upstream flow and part by downstream, and such chambers frequently had pressure loss factors of 40-50. With the introduction of the straight through chamber, the P.L.F. was reduced to 25 or thereabouts, and steady development since that time has enabled lower and lower P.L.F.'s to be obtained in suitable chambers.

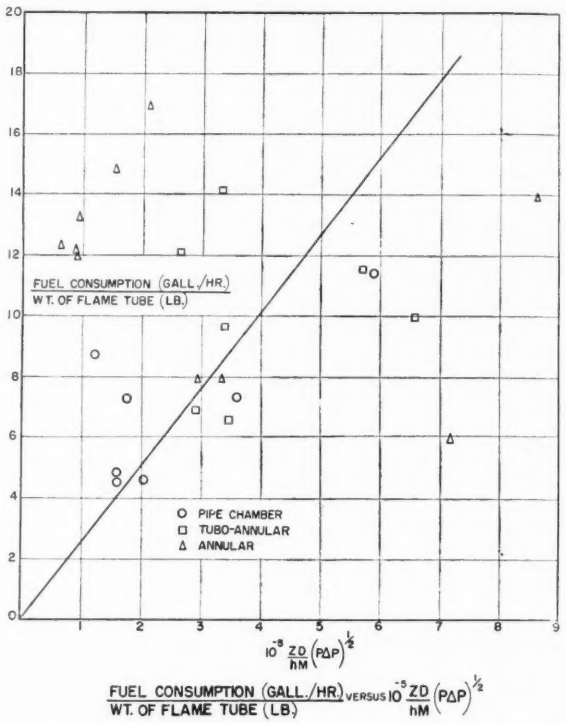

FIGURE 10. Fuel consumption per lb. wt. of flame tube.

This does not mean that the pressure loss itself has been reduced, but rather that the decreased restriction in the chamber has been exploited for the purpose of enabling higher and higher throughputs to be handled. The throughput loading is usually expressed in terms of the Mach number of the inlet flow based on the area of the maximum cross section, and if this Mach number be squared, and multiplied by the P.L.F. and by half the ratio of the specific heats of air then the product is equal to the fractional pressure loss.

It therefore appears that for a given Mach number, the fractional pressure loss and the P.L.F. are proportional to one another, but if the throughput Mach number is raised, which has been the trend with high performance engines over the years, then the same standard of fractional pressure loss (*i.e.* the same repercussion on the cycle efficiency) means that a lower P.L.F. must be achieved, which is equivalent to a more " opened up " chamber as regards hole sizes, and so on.

The trend of rise of throughput Mach number since 1941 is such that there is a progressive increase in the maximum velocity in chambers which can be designed for high performance aircraft engines of various types, while there will continue to be a demand for the moderate velocity types for other applications.

At the same time, the relationship of fractional pressure loss to heat release must not be overlooked. A recent paper by the author[7] has dealt with this subject in full, but the theory can be outlined briefly as follows.

The immediate function of the pressure loss across the flame tube wall is to cause a certain velocity of

injection of the primary air into the flame tube. It is upon the streams of this air that the toroidal vortex rolls, and the system of velocities within it is therefore determined. An integration across it now enables the circulating mass flow to be determined, and thus the fuel flow which the vortex is capable of burning.

This fuel flow may be written as a specific heat release in the units mentioned elsewhere in this paper, namely C.H.U./(ft.^{2} hr. atm.), and when the necessary algebra is worked out, it is seen that the heat release is proportional to the square root of the fractional pressure loss across the flame tube wall. Comparing the fuel burning capacity of the vortex with the fuel actually burnt in a pipe chamber, we see that in a typical case, only one quarter of this fuel at most can be burnt in the vortex, and the bulk must therefore be burnt further downstream in the intermediate portion of the flow pattern.

Attempts have been made to investigate this by determining the distribution of gas composition throughout the primary vortex of a typical pipe chamber. The practical difficulties of this work are obviously great, and in particular, the technique of taking a fair sample of the unevaporated fuel at a given point.

The work done up till now has therefore only covered the exploration of the distribution of the gaseous part of the contents of the primary zone. The gaseous mixture strength has been found to be in the region of stoichiometric throughout this zone, and the concentration of gaseous unburnts has been found to be greatest near the flame tube wall, and least on the flame tube axis.

In the case of spray systems, performance improvements had to go hand in hand with improvements in the sprayer system. This is particularly with respect to the methods of obtaining satisfactory atomisation over a wide range of fuel flow rates, which has given rise to the necessity for using special types of atomiser such as the Duplex type shown in Fig. 11, in which the lower ranges of fuel flow are delivered through the central or pilot atomiser only while the higher fuel flows are delivered through the two atomisers in combination.

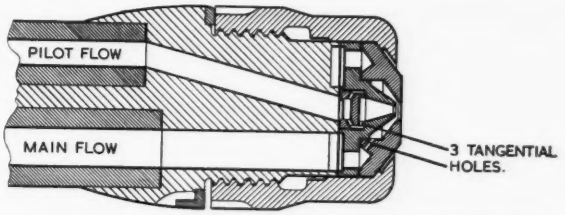

FIGURE II. Diagrammatic cross section of Duplex sprayer.

As a result, the atomising pressure can be maintained at a fairly high value over the whole range of running conditions, a matter which is important from two points of view. On the one hand, the velocity of discharge of the fuel spray from the atomiser orifice is dependent directly upon the pressure, and a certain minimum is necessary to enable the spray to penetrate effectively into the primary zone flow pattern.

On the other hand, rapid evaporation is dependent upon the spray being atomised to a sufficiently fine degree as expressed by the mean droplet size, or Sauter Mean Diameter, as it is termed.

Figure 12 shows the effects of this S.M.D. upon the combustion efficiency at the idling condition in the case of two typical comparable pipe chambers, one being provided with upstream spray injection and the other with downstream. Besides showing the general trend towards poorer efficiencies with larger droplets, the curves also bring out the point that an upstream system is capable of tolerating larger droplets because they have a greater residence time in the primary zone, and consequently a better opportunity to evaporate.

The very fact that an atomised fuel spray contains a wide variety of droplet sizes can be turned to good account in the process of mixing the fuel and the air intimately in the primary zone. For, if the fuel spray is injected at right angles to the local direction of the vortex stream lines, then the smaller droplets will be earliest diverted into the vortex, while the largest will have the deepest penetration.

Figure 13 shows a typical histogram of droplet size

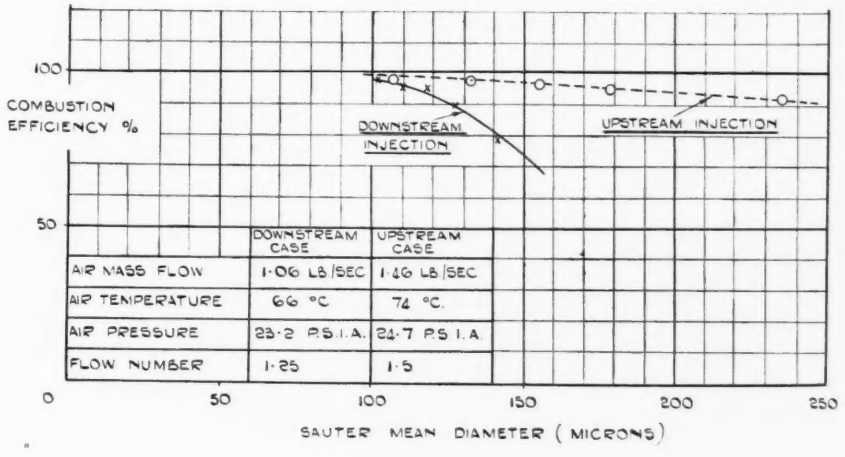

FIGURE 12. Comparison between upstream and downstream fuel injection curves of combustion efficiency/Sauter Mean Diameter.

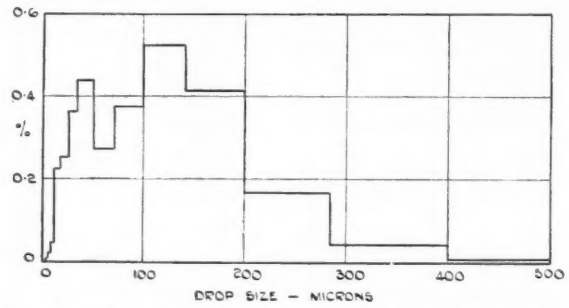

FIGURE 13. Typical droplet size distribution from swirl atomiser per cent. by volume per micron of group interval.

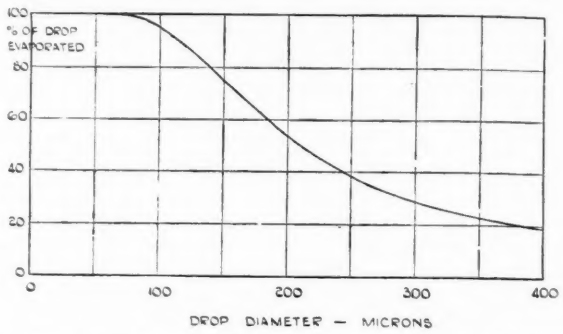

FIGURE 15. Percentage of droplet evaporated on leaving vortex.

distribution covering a size range of 100 to 1 in diameter, *i.e.* 10^6 to 1 in droplet volume. Fig. 14 shows the trajectories of these droplets in a particular pipe chamber vortex in which a number of simplifying assumptions have had to be made to enable the theoretical calculations to be performed.

In this particular instance, a considerable part (28 per cent.) of the spray remains unevaporated on leaving the vortex, and Fig. 15 shows how this unevaporated part is composed. Droplets of 80 microns diameter and less are completely evaporated while those of several hundreds of microns are scarcely evaporated at all. These latter, however, are so few in number that this fact is not responsible for the falling off of evaporation efficiency. It will be seen from Fig. 16 that it is the droplets of 200 microns diameter and thereabouts that are chiefly responsible for this fall-off.

6. Development of Specific Chambers

It may be of interest to record here that the dimensions of a combustion chamber to fulfil a given duty within the scope of existing experience are first calculated theoretically, and then after detailed mechanical design, the prototype chamber is manufactured for the test rig.

It will be appreciated that in the case of annular chambers very large air supplies would be required to perform full scale tests of this type. This problem can be overcome in different ways, but it is generally considered that the testing of sectors of the complete chamber is not a good thing. This applies particularly to the testing of sectors of fully annular chambers, but even with tubo-annular chambers, the use of a sector can give misleading results. A sector can admittedly give a good impression of the length and character of the flame, but the temperature traverse measurements are particularly prone to be in error.

It is therefore preferred to test at atmospheric pressure and to use to the full the growing knowledge of scale effects in combustion chambers. In view of past experiences, however, it is felt that in the long run development is retarded if these devices become necessary, and that fully annular testing is always desirable.

Arising from the application of the above methods, the Rolls-Royce Dart, Napier Eland, D.H. Ghost and Bristol Proteus are examples of pipe chambers which have been developed in association with the gas turbine engine manufacturers and their flame tubes are illustrated in Figs. 17 to 20.

7. Ignition

In spite of a good deal of argument, it is now accepted that the progress of ignition proceeds

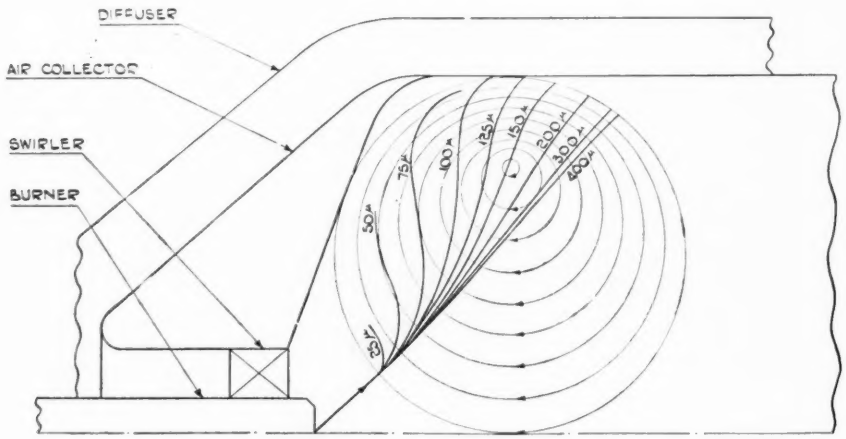

FIGURE 14. Paths of droplets of various sizes through the vortex.

according to the thermal theory, which states, in effect, that the problem is that of releasing sufficient energy in the form of heat at the right place and in the right time. Much research on ignition in recent years has brought nothing to light which serves to cast any doubt on this theory.

It appeared that great economy in the ignition energy required could be obtained by concentrating it into separate strong pulses of short duration, with a relatively great time interval between them. This led to the need for an electrical energy storage device, and the electrostatic condenser was the obvious choice.

Attention must be drawn to the fact that this storage condenser must handle a considerably greater energy than that required at the spark itself. Losses in the circuit and reduced voltage of the spark once the ionisation occurs are factors which prevent high efficiencies from being reached.

To quote an example, a 12 Joule system is one in which the condenser contains 12 Joules when fully charged, but fully half of this is released elsewhere than at the plug gap when the discharge occurs. Again, the efficiency may well be halved by the resistance of the plug leads, even for values of only a fraction of an ohm.

Not only is the energy released at the plug a mere fraction of that stored in the condenser, but also the energy released at the plug is by no means all released as heat. Besides a considerable electromagnetic output of light, and so on, from the plug, there is the fundamental fact that part of the energy potentially

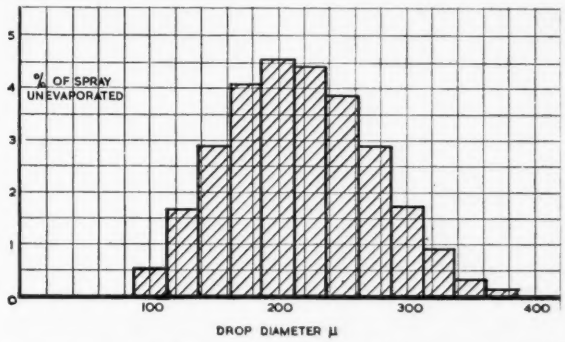

FIGURE 16. Distribution of unevaporated spray over droplet size range.

available as heat can only cause expansion of the local gas kernel by doing mechanical work upon the surrounding gas instead, as indicated by the strong shock waves shown in Fig. 21. These reach a diameter of 3½ inches in 105 microsec and 5 inches in 150 microsec, having started their expansion at a Mach number of approximately three, and reducing quickly thereafter to sonic velocity.

The Schlieren technique of examining the ignition process has led to a great deal of fundamental knowledge. The growth in time of the hot kernel of gas generated by the spark may be observed, and from this may be deduced the amount of energy release in the form of immediate heat. It is also apparent that some

FIGURE 17 (*left*). Flame tube for Dart engine (Rolls-Royce Ltd.).

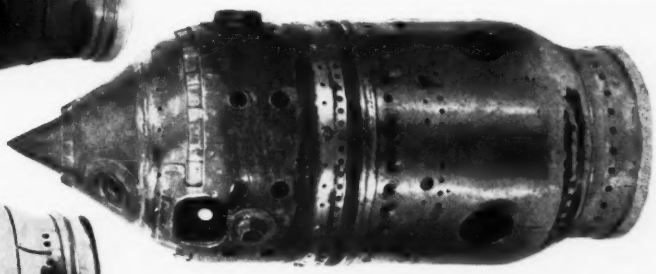

FIGURE 18 (*above*). Flame tube for Eland engine (D. Napier and Son Ltd.).

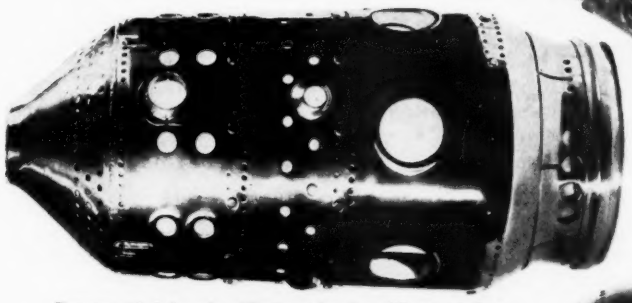

FIGURE 19 (*above*). Flame tube for Ghost engine (The de Havilland Engine Co. Ltd.).

FIGURE 20 (*right*). Flame tube for Proteus engine (The Bristol Aeroplane Company Ltd.).

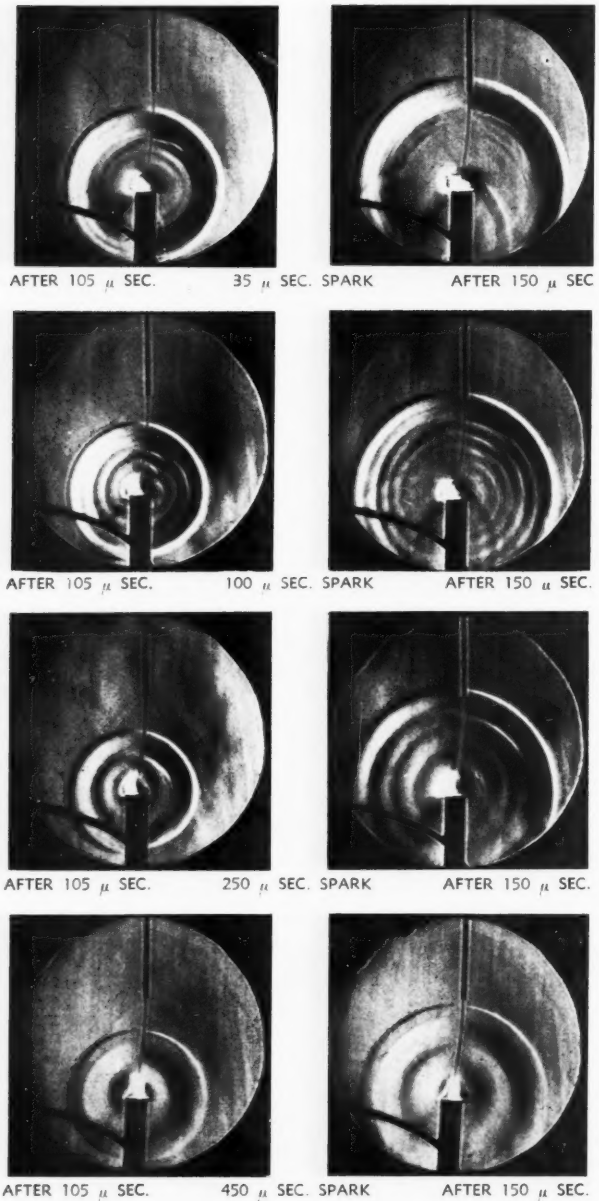
AFTER 105 μ SEC.
35 μ SEC. SPARK
AFTER 150 μ SEC
AFTER 105 μ SEC.
100 μ SEC. SPARK
AFTER 150 μ SEC.
AFTER 105 μ SEC.
250 μ SEC. SPARK
AFTER 150 μ SEC.
AFTER 105 μ SEC.
450 μ SEC. SPARK
AFTER 150 μ SEC.

FIGURE 21. Schlieren photographs of shock waves due to a high energy surface discharge spark.

of the energy goes to heat the plug surface in the first instance, and is then given off into the kernel after the discharge has ceased. An optimum discharge duration of 100-200 microsec has been established, as lower rates cause too cool a kernel while higher rates cause too much of the energy to be wasted in electromagnetic and acoustic radiation.

A typical aero gas turbine pipe chamber has been chosen as the vehicle for extensive exploration of the effect of certain parameters on the ignition process. Fig. 22 shows the relation between absolute air pressure

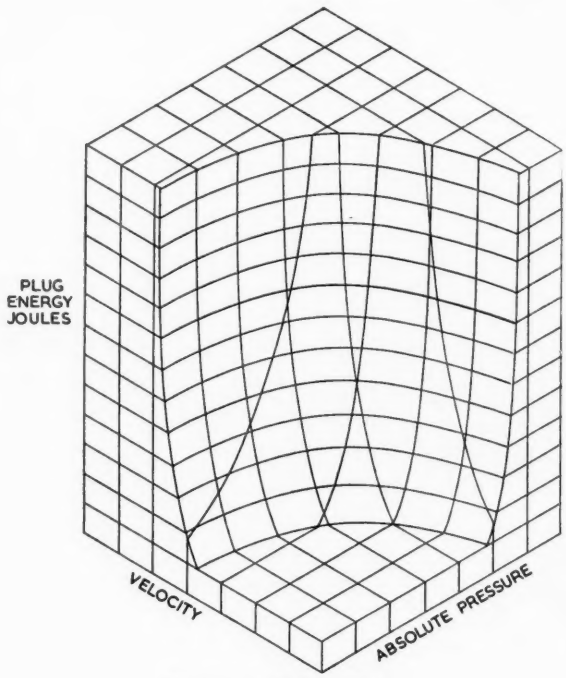

FIGURE 22. Ignition limits.

in the chamber, local air velocity in the neighbourhood of the electrodes and required spark energy (stored in the condenser).

The limits may be extended a little by the use of finer atomisation, but the overall impression still remains that very little improvement is to be expected from sparks of a higher energy.

The usual means of relighting at altitude is by allowing the engine to windmill by the application of ram pressure. It is not commonly realised that the local air velocity at the plug is then often higher than at the full load condition if the turbine is anywhere near choking. This is because the temperature ratio across the chamber is then only 1 as against 2 to 2½ in the full load case.

As a result of this, and since the local air velocity in the vicinity of the plug is proportional to the full section chamber velocity, the problem of relighting from windmilling conditions at a high altitude is one of the most stringent requirements such a combustion system has to meet.

8. Choice of Materials for Flame Tube Operating Conditions

In the early days of development flame tube life was short, due mainly to the high temperature of operation. Failures by creep due to steep thermal gradients were experienced and there was severe cracking at the edges of welds by fatigue and at the edges of holes. Improvements in design and construction largely overcame the first two problems, but it was some time before it was realised that the cracking at holes was probably mainly

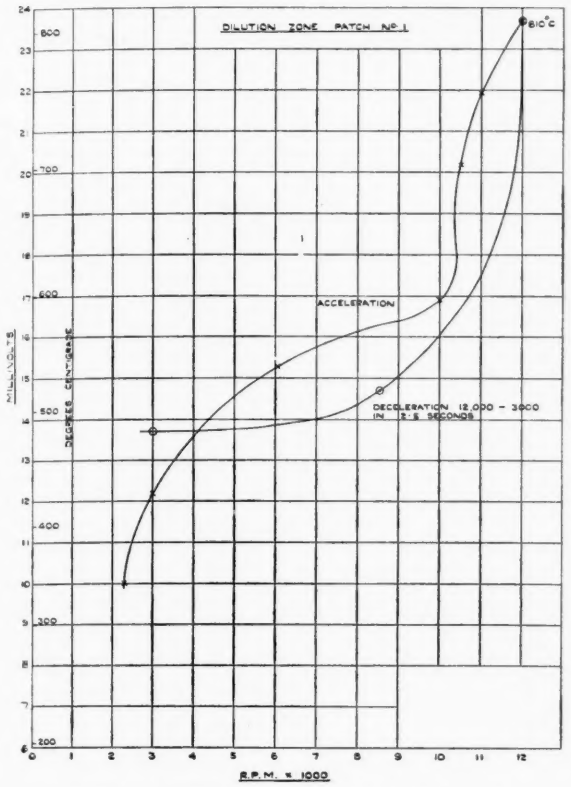

FIGURE 23. Flame tube temperature measurements (Nene Mark I engine).

due to thermal fatigue. This is the type of fatigue which arises from alternations of temperature caused by repeated acceleration and deceleration of the engine.

Originally an austenitic steel was used for flame tube construction but gave very short life. This was replaced by Inconel with some improvement, and later by Nimonic 75.

When the significance of the rapid change of flame tube wall temperature due to acceleration and deceleration of the engine was appreciated, work was started on this problem. Measurements of temperature of the flame tube walls were made during engine tests, and Fig. 23 shows typical values of instantaneous temperature during rapid acceleration and deceleration. In the light of such results as this, a thermal fatigue test was devised to reproduce these conditions as closely as possible. Fig. 24 shows a diagram of the apparatus used.

In this test, the specimen is in the form of a 4 in. square of sheet metal with a round hole pierced in the centre. The edge of this hole is radiused and polished in accordance with standard manufacturing practice, as this has been found to give the longest life. Specimens are tested in pairs; while the left-hand specimen is in the flame, the right-hand specimen is subjected to a cooling blast of air. At the end of one minute, the left-hand specimen moves over into the cooling zone and the right-hand specimen into the flame. The test continues until a crack develops. the number of cycles of operation being the thermal fatigue index. Fig. 25 shows a view of the actual machine.

Initial tests were made on 0.048 in. thick specimens of Nimonic 75 with a temperature cycle ranging from 20°C to 900°C, and a basic figure of 220 cycles to failure was obtained. Fig. 26 shows the results of similar tests covering a range of different thicknesses, and it will be seen that the thinner gauges have the longer life.

Figure 27 shows the effect of varying the maximum temperature of the cycle upon the number of cycles to failure, and demonstrates the great advantage to be gained by a reduction of flame tube wall temperature. Tests have been made on other materials suitable for flame tubes and the results are shown on Fig. 28.

Rig testing of the complete flame tube under combustion conditions is often able to show whether the actual temperatures achieved are acceptable from the point of view of life. This is with special reference to the cyclic testing in which the flame tube temperature is caused to alternate periodically between its steady maximum value and a low temperature, and the effects

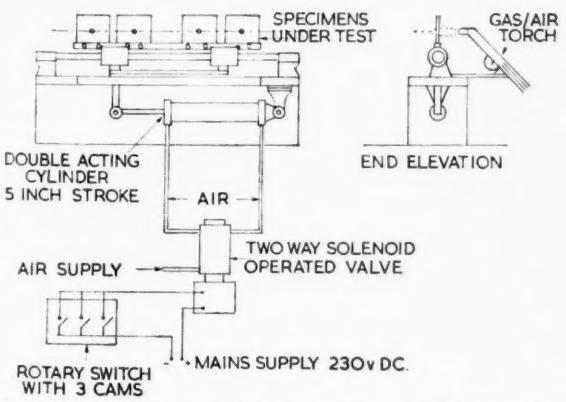

FIGURE 24. Diagrammatic layout of thermal fatigue testing machine.

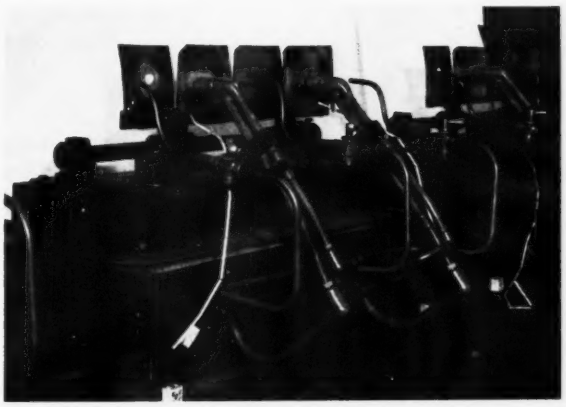

FIGURE 25. Thermal fatigue testing machine.

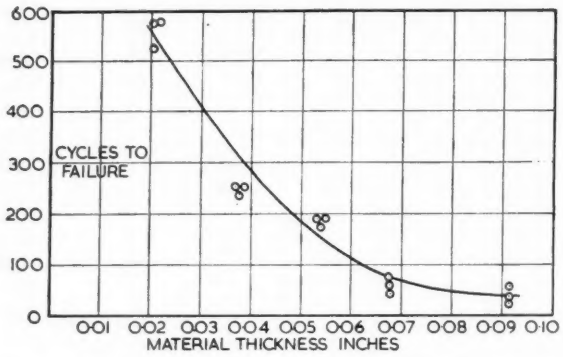

FIGURE 26. Variation of thermal fatigue life of Nimonic 75 with variation in material thickness tested at 900°C.

of creep and thermal fatigue are then quickly brought to light.

In conducting such tests, it is often found that higher metal temperatures are reached on the engine itself than when using a combustion chamber test rig with an in-line combustion preheater, because of the difference of maximum primary zone temperatures in the two cases.

The maximum primary zone temperature attainable depends upon the composition of the fuel and oxidant and upon their initial temperatures, and it must be remembered that on the combustion test rig the initial temperature is that at inlet to the preheater, which may be 200°C or more cooler than that in the engine case. When it is remembered that the flame radiation heat transfer proceeds according to the 3rd or 4th power of the flame temperature, it will be realised that there can be a serious difference.

Also it must not be forgotten that different parts of the equipment will inevitably reach different steady temperatures at any assigned running condition, and that these temperature gradients themselves cause stresses which can only be minimised by designing in the light of a full appreciation of the exact mechanism which causes them.

Thus it comes about that, in certain applications, quite a high metal temperature (800-900°C) can be tolerated with no detrimental effect upon life, while in other cases a temperature of only 650-700°C may be too high.

A development of considerable interest in this connection is Nimoply, a laminated material with an inner layer of copper protected by outer layers of Nimonic 75, although difficulties of bonding in producing this material have yet to be finally overcome. The high thermal conductivity of the copper reduces temperature gradients and helps to eliminate hot spots, thus reducing thermal stresses, an important factor in obtaining increased life.

The temperature at any point in the system arises as the result of a balance between the radiative, convective and conductive heat transfers between that point and the remainder of the system, and there is now a

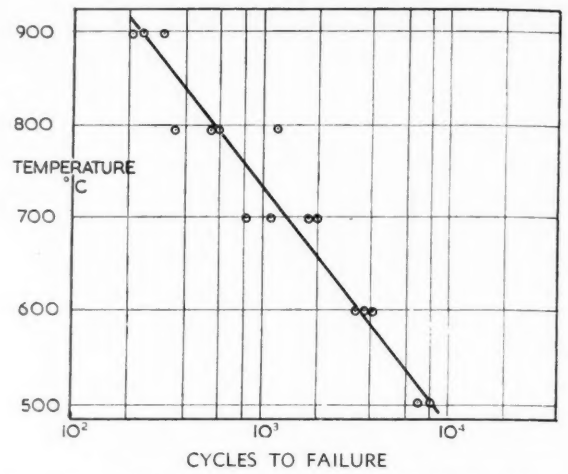

FIGURE 27. Thermal fatigue curve for Nimonic 75 over range of temperatures.

considerable body of experience and theoretical knowledge which enables these temperatures to be forecast with some accuracy at the design stage.

Following the realisation of the advantages to flame tube life by a reduction of wall temperature, various methods of skin cooling were tried and incorporated into engines.

In one method, known as the internal ring or skirt, a sheet metal ring of slightly smaller diameter than the flame tube is fastened inside the tube by means of rivets which space it to a certain annular clearance all the way round the perimeter. Two rows of small holes admit air from outside the flame tube into this annular clearance from which it emerges in the form of a skin cooling film passing downstream in contact with the interior of the flame tube wall. Examples of this method can be seen in Figs. 17, 18, 19 and 20.

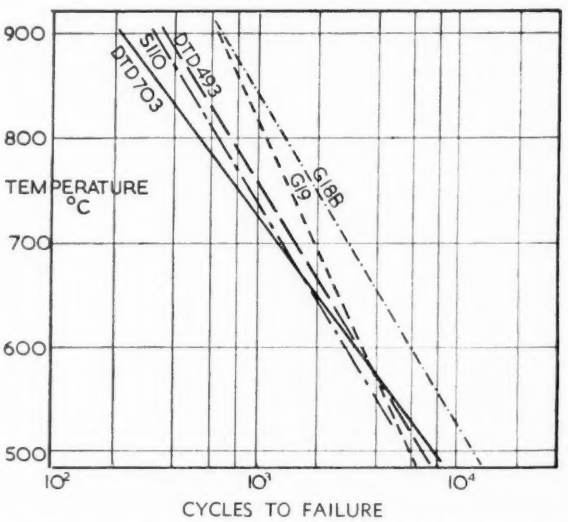

FIGURE 28. Thermal fatigue curves for D.T.D.703 (Nimonic 75), D.T.D. 493, S110, G18B and G19.

This method uses only the static pressure drop across the flame tube wall as the driving force for the cooling air admission. In high velocity or low pressure loss combustion chambers, however, this pressure drop may be too small, and it may therefore be essential to use the total pressure drop instead. This may be done by the method referred to as the "wigglestrip", an example of which is to be seen at the upstream end of the primary zone and again on the snout of the flame tube in Fig. 18 in Section 6. This consists of an annular clearance and overlap between successive portions of the flame tube, the clearance being occupied by a corrugated circumferential strip.

The development of skin cooling brings in its train the possibilities of using less expensive materials than Nimonic 75.

9. Acknowledgments

The author's thanks are due to the Ministry of Supply, and to the Directors of Joseph Lucas Limited, for permission to publish this paper. He would also like to thank Rolls-Royce Ltd., D. Napier & Son Ltd., the de Havilland Engine Company Ltd. and the Bristol Aeroplane Company Ltd., for permission to include photographs of flame tubes associated with their engines.

The author's sincere thanks are also due to his colleagues in Burnley for all the work that has been done, particularly to Dr. A. E. Clarke and Mr. G. J. Hudson, M.A., A.F.R.Ae.S., for their work in collecting the data contained in this paper.

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DISCUSSION

K. R. DAVIES (Rolls-Royce Ltd., *Associate Fellow*): Although the lecture had been most interesting and comprehensive on the engine side, he regretted that Dr. Clarke had not touched on the reheat combustion problem. As far as he was concerned, being a reheat development engineer, combustion in the engine appeared to be the easier side of the problem! Dr. Clarke could use a nice fat pressure drop that was denied to the reheat combustion engineer.

Dr. Clarke had described the different types of cans, the old type of can, the tubo-annular and finally, the completely annular can. It seemed to him that having gone to all the trouble to get a symmetrical chamber, Dr. Clarke rather glossed over what he would do with the fuel. Having made everything very symmetrical, to put a number of crude jets, even if they were fully atomised, round the system, seemed to him to leave room for improvement. He thought there must be some better way of dealing with that; such a thing as a flat spray perhaps or a centrifugal spray.

To return to the reheat side of the job, Dr. Clarke dismissed in very few words during discussion on stabilising in general, the crude type of stabiliser, the flat disc, or it might be an annular plate or annular gutter. He thought Dr. Clarke was probably saying that this inherently resulted in a very low efficiency or a long flame. In reheat combustion problems a gutter or cone was the basic type of stabiliser used and, in general, was satisfactory from an efficiency angle and had a very low pressure loss. He would be very interested to know whether Dr. Clarke had in mind other types of stabilisers that could be used in a reheat system.

P. F. ORCHARD (Bristol Aero Engines Ltd., *Graduate*): Dr. Clarke had said about modern engines with high combustion chamber inlet temperature, due to the high engine Mach number, that there would be less dilution air available, but it seemed to him that with a high inlet temperature they could stick to the same fuel/air ratio and get approximately the same temperature rise in the combustion chamber: they would get the same proportion of dilution air but a correspondingly higher turbine inlet temperature, so they would have about the same amount of dilution air available to do the mixing with. Similarly, another point with high Mach number engines, the high inlet temperature to the combustion chamber brought some benefit in providing a much higher chemical reaction rate available, due to the high inlet temperature which was available there without being vitiated by combustion products. Dr. Clarke had mentioned that the vitiation in the recirculation pattern might cause trouble, but this vitiation also resulted in a higher temperature at the points vitiated in the recirculation pattern and as the reaction rate in general had a

logarithmic relation with temperature, and nowhere near such a severe relation with the vitiation, he felt that the more vitiation, or the more proportion, that could be recirculated the better because the reaction rate would go up with the temperature.

Coming to the recirculation patterns that Dr. Clarke delineated, he had often wondered if lower pressure losses might not be obtained if they made more attempt to direct the inward injected air. At present they left the air just to flow as it would through holes in the side of a flame tube, whereas in the early days the Germans made some attempts to provide directing pipes and baffles to cause physical recirculation, rather than rely on a pressure drop and rough direction of the air. If more attempts were made to get hold of the air and direct it with aerodynamically shaped baffles he felt that they might get an efficient recirculation pattern with lower loss.

One major point that had to be made in favour of tubo-annular and fully annular systems was that the back-bone of the engine could be moved out to a much greater diameter with these two systems and resulted in a much better mechanical efficiency of the engine as a whole. With a pipe chamber there was a series of small connecting pipes from the compressor to the turbine which could not be used to take any of the stress or the loads to the compressor and the turbine; they had to rely on a small "milk churn," as Dr. Clarke called it, whereas on the tubo-annular or the fully annular chamber they could put that member right out to the maximum diameter of the engine and so get a more efficient member.

He would agree with the last speaker about the flow patterns for a fully annular chamber; it had never seemed to him to be correct that with a fully annular chamber they should try to duplicate the flow pattern that was set up in a tubo-annular one. He also would ask for a flat spray and a fully annular vortex, rather than a series of discrete vortices left on their own in a fully annular space.

He would suggest that the number of dilution holes in a pipe or tubo-annular flame tube was tied to the penetration that was needed to get mixing dilution air right to the centre of the flame tube and the magic figure of four was by no means always the best. With a small diameter flame tube or plenty of pressure drop available, they would be better off with a larger number of smaller holes, provided that they could get the penetration to the centre of the flame tube, because they then had more streams of cold air mixing with the hot gases from the primary zone.

Where had Dr. Clarke taken his samples from the primary zone showing the results of combustion efficiency and mixture strength? It seemed to him that if Dr. Clark had incompletely burnt gases near the walls, if those were taken sufficiently far forward there was a chance that some of those gases would be recirculated and burnt later on in the pattern in the primary zone itself.

J. L. EDWARDS (Assist. Chief Engineer, de Havilland Engine Co. Ltd., *Associate Fellow*): The multiple curve presented in Fig. 1 appeared to show the relationships between the pressure drop of a combustion chamber and flight condition. The curves did not, however, appear to be qualified by the quality of the temperature traverse at entry to the combustion chamber.

Recent experience with high temperature engines had shown that if good mechanical reliability were to be achieved, the temperature profile was by far the most important individual quality of a combustion system. The chamber had to be designed to give a distribution which would match the stress characteristics of the turbine blades and give as nearly as possible the same creep life at all sections. The achievement of this aim was far from easy, and it was possible that to attain it, far from being able to reduce the pressure drop of the combustion system from its present level it might have to be materially increased. Dr. Clarke's views would be appreciated both as regards this particular point, and the possible repercussions of such a change in philosophy on the curves shown in Fig. 1.

Another consideration was the effect of the change of conditions in the combustion chamber at high aircraft Mach numbers. Changes in reference velocity of the order of 100 per cent. could take place between sea level static and a Mach number of 2·5 and these were accompanied by corresponding changes in combustion intensity. Which of these two quantities, namely, reference velocity or combustion intensity, did Dr. Clarke think was the more important? Further, did he consider that the Mach number in the combustion chamber had any significance in itself, or was its use merely a convenient way of coupling velocity and temperature?

Agreeing with Mr. Davies, it was a pity that Dr. Clarke had not made more mention of reheat. The problems were somewhat different from those associated with the combustion chamber. The requirements for temperature traverse for example, were very different in that with reheat one had to maintain a cool layer of air adjacent to the metal walls, but the maximum temperature at the centre of the gas stream was relatively unimportant; with a combustion chamber, one had to have a predetermined temperature gradient over the outlet area, and wall cooling was accomplished by other means. Nonetheless there were certain fundamental characteristics associated with reheat which could not be ignored, and it was a little disturbing to hear Dr. Clarke talking about a cylindrical engine of constant diameter. The modern trend was to reduce compressor,combustion chamber and turbine diameters and then to try and bring the reheat combustion zone into line. Unfortunately if this process were taken too far, it would result in a severe loss of reheat performance. It behoved the aircraft and engine manufacturers, therefore, to weigh the merits of the very small tailpipe, against the severe performance penalties which it would undoubtedly entail.

S. L. BRAGG (Rolls-Royce Ltd., Derby): He wanted to emphasise two points in Dr. Clarke's paper. The first was the question of fuel/air ratio; he did not know if anyone in Merthyr Tydfil still owned an old-fashioned car, but they would remember that they were very difficult to start, mainly because the air/fuel ratio was difficult to control at the right value. In fact, the car people took a lot of trouble with carburettor design to get the air/fuel ratio just right. Unfortunately, in the gas turbine, one could not put a throttle in front and keep the air/fuel ratio constant, as on a car, because it spoiled the efficiency of the cycle. So one simply put in very much less fuel, and ran with a much weaker mixture under the low speed conditions. That meant that one had to build a combustion chamber that would still keep burning over a wide range of mixture conditions.

The fact that the combustion chambers that Dr. Clarke had designed did this was, to a certain extent, a measure of imperfection, in that, if the chambers were so uncritical that they would accept any air/fuel ratio between, say, 60 to 1 to 200 to 1 or 2,000 to 1, they must be a very long way from the optimum. One always found that the closer one got to something that was ideal the more critical it was. For example, one could do anything with a centrifugal compressor, but the efficiency was low. On the other hand, an axial compressor needed nursing; it was frightfully critical but very efficient.

He wondered if in this new breed of combustion chambers one should not try to make them much nearer the ideal air/fuel ratio all the time so that they could be smaller and more efficient; in so doing there would have to be some sort of complicated air/fuel ratio control. Did Dr. Clarke think that air/fuel ratio controls were a necessity for the future breed of combustion chambers?

The second point arose because the jet engine only operated efficiently when it was flying fast and high. High altitude operation raised all sorts of nasty problems of combustion. In particular the necessity of shutting the throttle and idling at 40,000 ft. while waiting for permission to land, meant that combustion chambers must operate at air pressures of 1 or 2 p.s.i.a. He wondered whether in planning both aircraft operation and aero-engine operation the limitations of the combustion chamber were really taken into account.

When he first started in gas turbine work, the process of engine design was, first to think of a size of engine that it would be nice to make, then to design the compressor, going through all the blade calculations, aerodynamics and so on, and then to design the turbine: next one put a shaft in between the compressor and turbine and designed it so that it was the right size and did not whirl; finally one squeezed the combustion chambers into the space that was left, and relied on Dr. Clarke's ingenuity to make them work.

Did Dr. Clarke think there was any chance of combustion chamber limitations being treated as a fundamental in aero-design and that aero-engines might be built round the combustion chambers, rather than the combustion chambers being fitted in last?

DR. CLARKE'S REPLY

MR. DAVIES:—With regard to Mr. Davies' contribution about available pressure loss and the use of a simple baffle, with particular reference to reheat combustion systems, he could not foresee at present a much better system than they now had; that was to say, the gutter, the baffle, or its variants. There was no doubt, however, that the vast amount of work currently being done on flame stabilisation would give greater knowledge. Mr. Bragg's own paper on screeching and the acoustics of these high velocity flames, he thought, would probably prove that such baffles would have to be non-circular. He felt that this was the logical line of future development.

He fully agreed with the remarks made by both Mr. Davies and Mr. Orchard on the geometrical inconsistency between the fully annular combustion space and the set of toroidal vortices. It did appear that it was not a good match. Both Mr. Davies and Mr. Orchard knew that attempts had been made to obtain a single or double fully annular vortex of the type called the "bicycle tyre" working in conjunction with the flat spray, but in order to get maximum efficiency, it was desirable to have the flat spray at the bottom of the chamber where it was not sufficiently accessible to form the basis of an acceptable engine design.

MR. ORCHARD: He agreed that with high T_2 due to ram, if T_3 were held constant, there would be a lowering in the cycle efficiency, and that, to avoid this, it was necessary to raise T_3 also.

Mr. Orchard's remarks on reaction rates being a function of T_2 and the general influence of this temperature on the kinetics were absolutely accurate, and all that seemed to be lacking for a full appreciation were some of the reaction constants which were now being investigated by the various physical chemists.

The "magic number" of four dilution holes represented good symmetry, and for a certain pressure drop it did give a very good temperature traverse, although it was not invariably the optimum number, and as Mr. Orchard said, the penetration was also a factor.

MR. EDWARDS: Referring to Mr. Edwards' question on the nomogram shown in Fig. 1, the pressure drop shown in the bottom left hand corner was expressed as a fraction (or multiple) of the value at the design point condition, and therefore the ratio would still apply whether the chamber had fundamentally a high or a low loss. There might be slight deviations, and strict accuracy within a few per cent. would not be claimed, but the nomogram was designed to give a presentation

of the effect of various engine conditions on the combustion chamber duty.

He agreed with Mr. Edwards that engine designers and engine development engineers would have to sacrifice a little pressure drop in the search for a better temperature distribution, but there was much good work being done today on mixing which would, he thought, probably restore the position.

The question of what parameter to use to express the behaviour of the combustion system under the many conditions was one which he would like to study in more detail. The paper did not attempt to deal with reheat as such, though obviously, much of the information could be read right across to it.

MR. BRAGG: Mr. Bragg had stressed the sensitivity of the ignition characteristics, with particular reference to the fuel/air ratio. The curves that they had presented in a different paper on the effect of fuel/air ratio on ignition suggested, and he was sure that he had the engine people with him on this point, that there was a need for very strict metering of the fuel in relation to the air and the starting conditions, whether at ground level or in flight. He felt that greater control was required because certain researches were showing the type of sensitivity mentioned by Mr. Bragg.

Whether his colleagues in the combustion field would ever get the engine designers' philosophy to be the combustion engineers' philosophy was a matter for much preaching and teaching and he was sure it was obviously desirable that the engine designer should understand the combustion engineers' problems to a greater degree. He did not think that even today the engine designer gave enough sympathy to the vexed problem of accommodating the combustion system.

He thought that Mr. Bragg had misunderstood the S.M.D. curve. The distribution of the spray inside the vortex as quoted was actually for droplets of the individual diameters mentioned, quite irrespective of their S.M.D.

VOTE OF THANKS

J. INGRAM (Chairman, Merthyr Tydfil Branch): He had listened to the lecture with a great deal of interest because, not being a combustion expert or even an engineering expert, he came with the firm intention of learning something about combustion. He must admit now that as soon as he saw the first chart he was a little horrified; he thought it was a dreadful chart and could not see how a layman without previous combustion experience, could understand what it was going to be about. However Dr. Clarke certainly went to work to tell them and he soon found himself entering into the lecture in more detail and he was very pleased indeed when Dr. Clarke admitted later on that a lot of the information obtained by the experts, including himself, was by the " suck it and see " method. He thought that the detailed way in which Dr. Clarke had answered the questions had added a great deal to the content of his lecture and he took great pleasure in thanking him very heartily on their behalf for the lecture.

DR. G. O. FORESTER: Like Mr. Ingram, he was a member of the local Branch and a non-specialist in this particular sphere. As laymen, he was sure that they were all aware of two types of combustion—the first, as in a paraffin lamp with a wick where there was burning at the interface between a vapour and air; the second, where there was mixing prior to combustion. This mixing appeared easier in the case of two gases, as in the household gas flame, but they also had a common example of the more difficult case, where paraffin had first to be atomised, in the blow-lamp. To a layman, then, it seemed rather surprising that there was such complication in getting good mixing and burning in gas turbine engines. However, that did not prevent him, and he was sure all the audience, specialist and non-specialist, from appreciating the vast amount of work that had obviously gone on at the Burnley laboratories and also in the preparation of the paper; it gave him great pleasure to second the vote of thanks to Dr. Clarke.

Recent Advances in the Knowledge of Transonic Air Flow

by

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1. Introduction

The most powerful theoretical tool in the solution of the aerodynamic problems of aircraft is the theory of small perturbations, which states that if a wing is thin (or a body slender), and if the incidence is small, then in inviscid flow the fluid velocity at any point can be treated as a small perturbation from the stream velocity. The backbone of our knowledge of the aerodynamics of aircraft is provided by this theory, to which the effects of thick wings and large incidences, and the effect of viscosity, introducing as it does the concept of boundary layers, can be added as additional or correction effects. It is known that at subsonic and again at supersonic speeds, the theory of small perturbations is a linear theory; that is, the assumptions implicit in it lead to a linear partial differential equation for the velocity potential, with linear boundary conditions. Not only does this make the equations relatively simple to solve mathematically, but more important, it implies that separate solutions for the velocity potential are additive, which means that thickness problems, and incidence, camber and twist problems, can be solved separately.

At transonic speeds it is found that the assumption of small perturbations does not in itself justify the use of a linear equation for the velocity potential, and as the resulting non-linear equation presents severe mathematical difficulties, there is a tendency to assume that theory is unable to predict what will occur at transonic speeds. While it is undoubtedly true that transonic theory is a long way behind both subsonic and supersonic theory, there have been a number of attacks in the past four or five years on the non-linear transonic theoretical problem, mainly two-dimensional, and a certain amount of prediction can now be made. It is the purpose of this paper to summarise some of this recent work.

The predictions of the small perturbation theory at transonic speeds will, of course, be limited to thin wings (and slender bodies) at small incidences in inviscid flow. These restrictions should not be too serious because to fly in the transonic region, power considerations alone will necessitate the use of wings and bodies that are sufficiently thin and slender for the assumptions to be plausible. Moreover, the effects of viscosity can probably be allowed for by usual boundary layer theory, for the shock waves that will occur on thin wings may not be sufficiently strong to cause appreciable boundary layer separation. The main limitation of the small perturbation theory is likely to be the restriction to small incidences, and for the present it must be accepted that we cannot predict what will occur in tight manoeuvres at transonic speeds.

It is a consequence of all small-perturbation work that the flow can be treated as irrotational and homentropic.

A Section Lecture given to the Royal Aeronautical Society on 4th January 1955.

NOTATION

A	wing aspect ratio
C_D	drag coefficient
C_{D_i}	lift-dependent drag coefficient
C_{D_0}	zero-lift drag coefficient
C_L	lift coefficient
C_P	pressure coefficient
c	wing chord
f, f_1, f_2	functional symbols, not necessarily implying the same function in different relationships
h	aerodynamic centre position as a fraction of the wing chord
L	distance of a detached bow wave ahead of the sonic point on a body
l	in Sections 2, 4 a typical length: in Section 3 the length of a body ahead of the sonic point
M	in Sections 2, 3, 4 the main stream Mach number: in Section 6 the local Mach number
M_{ml}	main stream Mach number below which the flow is entirely subsonic
M_{mu}	main stream Mach number above which the flow is entirely supersonic
M_{sl}	main stream Mach number at which the stern shock-wave is just attached to the trailing edge
M_{su}	main stream Mach number at which the downwind-going Mach line from the intersection of the sonic line and the bow shock-wave intersects the trailing edge
M_{tl}	main stream Mach number below which the flow is shock-free
M_{tu}	main stream Mach number at which the bow shock-wave is just attached to the leading edge
M_∞	main stream Mach number
m	position of the maximum thickness as a fraction of the wing chord
R	Reynolds number
r	semi-thickness of a body at the sonic point
t	diameter/length ratio of a body of revolution
V_∞	main stream velocity

x 'chordwise' co-ordinate
y 'spanwise' co-ordinate
z 'thicknesswise' co-ordinate
α angle of incidence, although also used in a generalised sense to denote a 'camberwise' scaling factor
Γ functional symbol representing the distribution of incidence, camber and twist
γ ratio of the heat capacities at constant pressure and constant volume
δ a small number
Θ functional symbol representing the distribution of thickness
Λ angle of sweepback
τ thickness/chord ratio of a wing, although also used in a generalised sense to denote a thicknesswise scaling factor
ϕ velocity potential
Ψ functional symbol representing the 'shape' of a body

2. Similarity Laws

Although the equation for the velocity potential at transonic speeds is difficult to solve, nevertheless one can, by studying the equation and the associated boundary conditions, deduce some relations between the pressures on bodies having affinely-related shapes, the so-called similarity laws.

Consider the case of uncambered wings at zero incidence. Two wings are affinely related if one can be made similar to the other by merely scaling up or down all the spanwise and 'thicknesswise' dimensions in, separately, the same proportion. The 'shape' of a wing will be denoted by the symbol Ψ, which will define the shape of the wing completely except for suitable spanwise and thicknesswise scaling factors, such as the aspect ratio A and thickness/chord ratio τ. The equation of the surface of a wing may therefore be written

$$\Psi\left[\frac{x}{l}, \frac{y}{Al}, \frac{z}{\tau l}\right]=0,$$

where l is a typical length. In such a case the pressure coefficient at a point

$$\left[\frac{x}{l}, \frac{y}{Al}, \frac{z}{\tau l}\right]$$

will depend on the shape Ψ, the aspect ratio A, the thickness/chord ratio τ, and, of course, the Mach number M: we may therefore write

$$C_P=f[\Psi; A, \tau; M].$$

Written this way, the pressure coefficient is a function of four parameters. At subsonic and supersonic speeds the well-known similarity laws show that this functional relationship can be reduced to one in which the dependence is on but two parameters, with all the simplification that this implies, namely*

$$\frac{C_P}{A\tau}=f[\Psi; A^2(M^2-1)].$$

*The functional symbols f do not necessarily imply the same function in the different relationships.

At transonic speeds the similarity law[1, 2, 3] shows that the functional relationship can again be reduced, but in this case to one in which the dependence is on three parameters, and although this is not so great a reduction as occurs at subsonic and supersonic speeds, it is nevertheless an appreciable simplification. The appropriate relationship may be written

$$\frac{C_P}{A\tau}=f\left[\Psi; A^2(M^2-1), \frac{M^2-1}{\tau^{2/3}}\right].$$

By changing the variables this relationship can of course be expressed in different ways, such as

$$\frac{C_P}{\tau^{2/3}}=f\left[\Psi; A\tau^{1/3}; \frac{M^2-1}{\tau^{2/3}}\right],$$

which is convenient if one is interested in changes of aspect ratio and of Mach number, because neither enters into more than one variable. In the case of aerofoils ($A=\infty$), the variable $A\tau^{1/3}$ may be omitted since its value is constant.

For bodies of revolution at zero incidence similar relationships can be obtained. For affinely-related bodies the pressure coefficient at a point may be written

$$C_P=f[\Psi; t; M],$$

where t, the diameter/length ratio, is the one scaling factor necessary for this class of body. At subsonic and supersonic speeds the similarity laws show that this functional relationship can be reduced to one in which the dependence is on two parameters, the dependence on one of them being of particular form, namely

$$\frac{C_P}{t^2}=f_1(\Psi)\log[t^2(M^2-1)]+f_2(\Psi).$$

At transonic speeds the similarity law[4] shows that, although the number of parameters in the functional relationship cannot be reduced, the dependence on one of them is of particular form, so that some simplification is achieved. The appropriate relationship may be written

$$\frac{C_P}{t^2}=f_1(\Psi)\log[t^2(M^2-1)]+f_2\left[\Psi, \frac{M^2-1}{t^2}\right].$$

By changing the variables this relationship can of course be expressed in different ways, such as

$$\frac{C_P}{t^2}=f_1(\Psi)\log t+f_2\left[\Psi, \frac{M^2-1}{t^2}\right].$$

The great value of the similarity laws is that they suggest parameters in terms of which experimental results should be analysed to make them applicable over as wide a range as possible. In the literature there are many examples of a collapse of experimental results that has been achieved by plotting in terms of parameters suggested by the similarity laws, and one such example will now be considered.

3. Bow Shock-Wave Detachment Distances

The distance of the detached bow shock-waves ahead of symmetrical two-dimensional and axially-symmetric bodies provides an interesting example of the use of

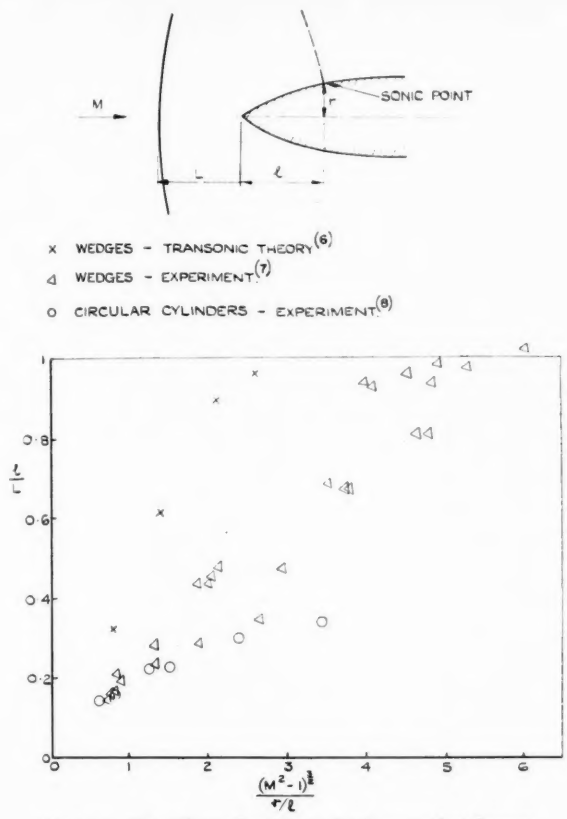

FIGURE 1. Two-dimensional bow shock wave detachment distances plotted against simple transonic parameter.

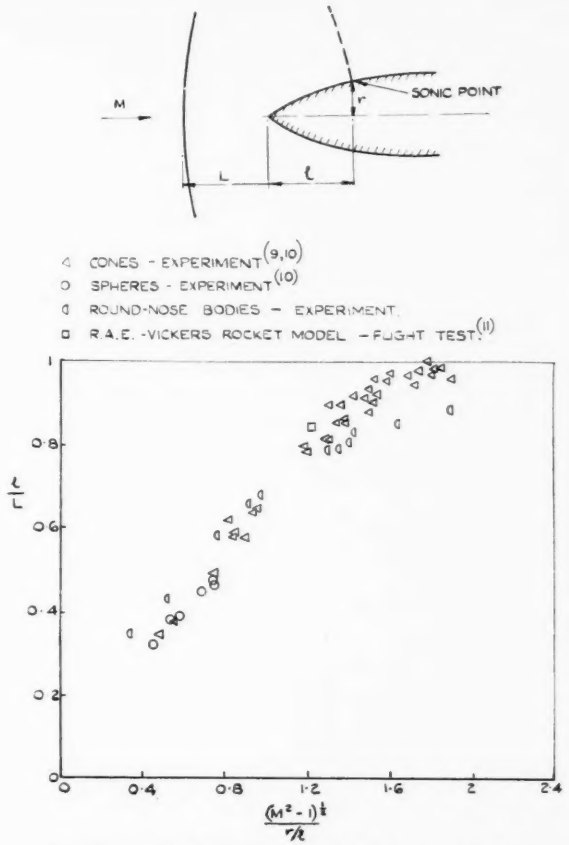

FIGURE 2. Axially-symmetric bow shock wave detachment distances plotted against simple transonic parameter.

similarity parameters to collapse experimental results. Since, as Moeckel[5] has pointed out, the detached bow wave is only secondarily influenced by the form of the body ahead of the sonic point, it is pertinent to consider the distance L of the detached bow wave ahead of this point, and if r is the semi-thickness of the body at the sonic point, to assume that L/r is a function primarily of Mach number, thus

$$\frac{L}{r} = f(M).$$

If the length of the body ahead of the sonic point is l, this may be written

$$\frac{L}{l} = \frac{r}{l} f(M).$$

Now r/l is a thicknesswise scaling factor when one is considering affinely-related bodies, and from Section 2 the appropriate transonic similarity parameter involving this and the Mach number is $(M^2-1)/(r/l)^{2/3}$ for two-dimensional bodies (aerofoils) and $(M^2-1)/(r/l)^2$ for axially-symmetric bodies. Therefore one is led to suspect that

$$\frac{L}{l} \propto \frac{r/l}{(M^2-1)^{3/2}}, \text{ for two-dimensional bodies,}$$

and $$\frac{L}{l} \propto \frac{r/l}{(M^2-1)^{1/2}}, \text{ for axially-symmetric bodies.}$$

Some experimental results for two-dimensional and axially-symmetric bodies respectively are plotted in Figs. 1 and 2. Actually, the reciprocals of the quantities already given have been taken as co-ordinates so that the ordinate shall range from 0 to 1. For bodies, such as wedges and cones, which have definite 'shoulders,' there is ample evidence to justify the assumption made that the sonic point is located at the shoulder, at least for the greater part of the transonic range from a Mach number of unity upwards. However, for bodies, such as circular cylinders and spheres which have curved profiles, the sonic point was located by an extension of a method suggested by Busemann.[12] This method locates the sonic point at a point where the profile is inclined at the maximum wedge or cone angle for an attached shock at that Mach number, as appropriate. It will be seen that rather poor collapses have been achieved in Figs. 1 and 2, particularly in the former which is for the two-dimensional bodies.

In Figs. 3 and 4 the same results are plotted again, but with a modified abscissa. Consider the two-dimensional case (Fig. 3). Here the abscissa has been modified from

$$\frac{(M^2-1)^{3/2}}{r/l} \quad \text{to} \quad \frac{(M^2-1)^{3/2}}{M^2\, r/l}.$$

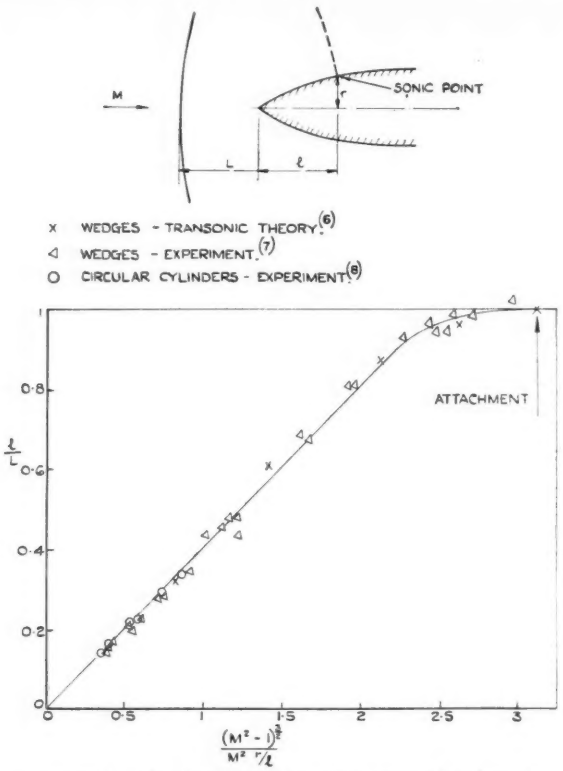

FIGURE 3. Two-dimensional bow shock wave detachment distances plotted against modified transonic parameter.

Transonic small perturbation theory, in which by definition M has a value around 1, treats these quantities as identical, and probably considers the latter an unnecessarily complicated form of the former. However, various authors have found that the second form tends to give better collapses of experimental results, particularly of results obtained at Mach numbers not particularly close to unity, and Spreiter[13] has indicated some reasons why this should be so. Many of the experimental results considered here are for Mach numbers of up to 2, which could not be called transonic in the small perturbation sense, but are transonic in the sense that one has a mixed-flow problem. The very good collapse achieved in Fig. 3 confirms the findings of other authors that, taking the two-dimensional transonic similarity parameter in the form

$$\frac{(M^2-1)^{3/2}}{M^2\, r/l}$$

makes the parameter applicable up to Mach numbers that could not be justified from considerations of small perturbation theory.

It will be noted from Fig. 3 that the modified transonic similarity parameter brings the experimental results into very good agreement with those of small perturbation theory. It will be noted also that the results for wedges and circular cylinders collapse on to essentially the same curve. For

$$\frac{(M^2-1)^{3/2}}{M^2\, r/l}$$

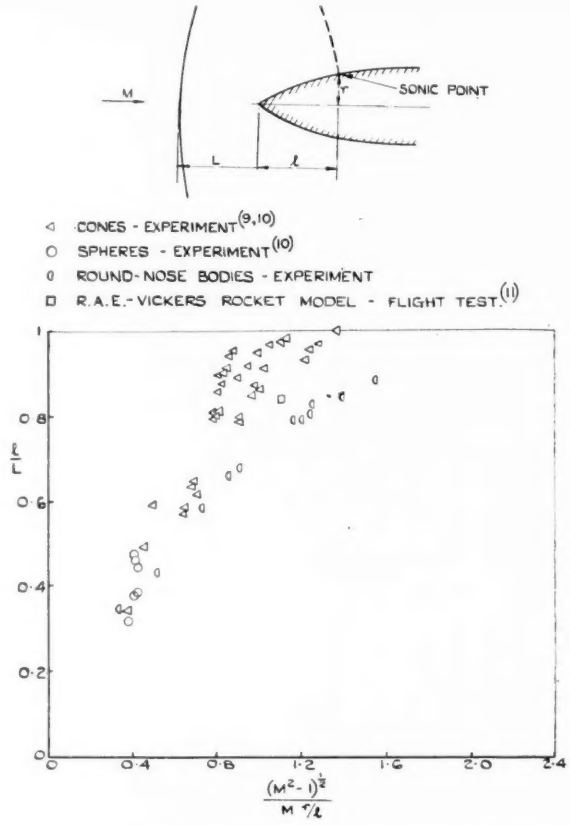

FIGURE 4. Axially-symmetric bow shock wave detachment distances plotted against modified transonic parameter.

less than about 2.25 the curve is linear, and the shock detachment distance is given very closely by

$$\frac{L}{r} = 2.47\,\frac{M^2}{(M^2-1)^{3/2}},$$

which, in keeping with Busemann's conjecture[12], is independent of l, the length of the body ahead of the sonic point. For

$$\frac{(M^2-1)^{3/2}}{M^2\, r/l}$$

greater than about 2.25, that is, near shock attachment, the curve shows that the shock detachment distance depends on l, and in this case it may well depend on the shape of the body ahead of the sonic point as well, but the results so far obtained are for one shape only, namely wedges. Small perturbation theory predicts shock attachment for wedges when

$$\frac{(M^2-1)^{3/2}}{M^2\, r/l} = \frac{3^{3/2}\,(\gamma+1)}{4} = 3.12.$$

Now Moeckel's simple geometric method[5] assumes that the shock detachment distance is equal to the length of a wedge of thickness equal to that of the body in question at its sonic point and angle equal to the

maximum wedge angle for an attached shock at that Mach number. This method yields

$$\frac{L}{r} = 3.12 \frac{M^2}{(M^2-1)^{3/2}},$$

which overestimates L, as Moeckel himself pointed out.

For axially-symmetric bodies there is hardly any evidence on the best modified form of the transonic similarity parameter. It will be seen from Fig. 4 that the modification of the abscissa from

$$\frac{(M^2-1)^{1/2}}{r/l} \quad \text{to} \quad \frac{(M^2-1)^{1/2}}{M\,r/l},$$

which appeared to yield the best improvement as regards collapsing the results, has been unable to bring the picture for the axially-symmetric case into as happy a state as has been achieved for the two-dimensional case.

4. Cross-Coupling between the Effects of Thickness and of Incidence, Camber and Twist

As mentioned in Section 1, a very important feature of subsonic or supersonic small perturbation theory, arising from the linearity of the partial differential equation for the velocity potential, is that separate solutions are additive, and thus thickness problems, and incidence, camber and twist problems, can be solved separately. At transonic speeds this is not so, and there is a cross-coupling between the two effects. Consider the case of wings. It will be convenient now to write the equation of the surface of the wing as

$$\frac{z}{l} = \alpha\,\Gamma\left[\frac{x}{l}, \frac{y}{Al}\right] \pm \tau\,\Theta\left[\frac{x}{l}, \frac{y}{Al}\right],$$

where Θ, Γ represent respectively the distributions of thickness and of incidence, camber and twist: τ, α are scaling factors for thickness and for incidence, camber and twist respectively. By similar reasoning to that in Section 2 the pressure coefficient at a point may be written

$$C_P = f\,[\Theta, \Gamma; A, \tau, \alpha; M].$$

At subsonic and supersonic speeds the similarity laws show that, as in Section 2, the functional relationship can be expressed as one in which the number of independent parameters is reduced by two, and moreover, that the dependence upon the effects of thickness and of incidence, camber and twist is separable, so that the relationship may be written

$$\frac{C_P}{A\tau} = f_1\,[\Theta, A^2(M^2-1)] + \frac{\alpha}{\tau} f_2\,[\Gamma, A^2(M^2-1)].$$

At transonic speeds, however, the similarity law shows not only that the functional relationship can be expressed as one in which the number of independent parameters is reduced by but one, but also that the dependence upon the effects of thickness and of incidence, camber and twist is inseparable, so that the relationship becomes

$$\frac{C_P}{A\tau} = f\left[\Theta, \Gamma; \frac{\alpha}{\tau}; A^2(M^2-1), \frac{M^2-1}{\tau^{2/3}}\right].$$

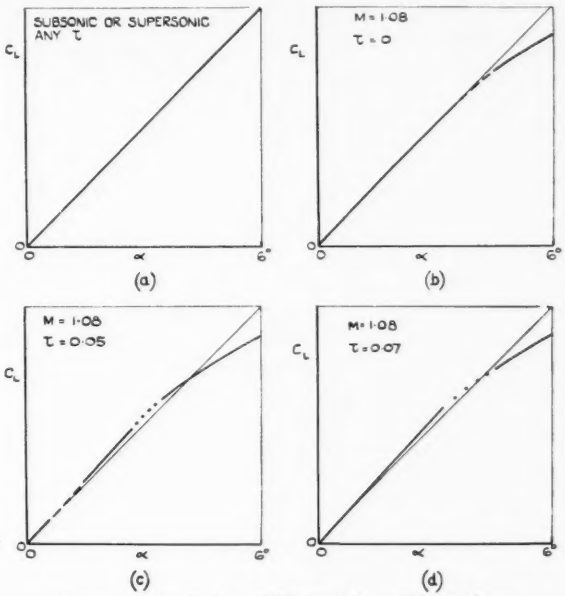

FIGURE 5. Variation of lift coefficient with incidence.

The implications of this are that, whereas at subsonic and supersonic speeds the pressure coefficient can be observed to vary linearly with either τ or α, at transonic speeds this is not so; although if α/τ, for example, is small than the function can be expanded as a Taylor series in α/τ to yield approximately

$$\frac{C_P}{A\tau} = f_1\left[\Theta, \Gamma; A^2(M^2-1), \frac{M^2-1}{\tau^{2/3}}\right] + \frac{\alpha}{\tau} f_2\left[\Theta, \Gamma; A^2(M^2-1), \frac{M^2-1}{\tau^{2/3}}\right],$$

which shows that in this case the pressure coefficient still varies linearly with α.

These implications of the similarity laws can be appreciated more readily by considering the variation of lift coefficient with incidence at various Mach numbers. Fig. 5(*a*) shows diagrammatically the linear variation of lift coefficient with incidence that occurs at subsonic or supersonic speeds for any thickness/chord ratio. Fig. 5(*b*) shows what one must expect at a Mach number near unity for the theoretical case of zero thickness/chord ratio. Initially the lift coefficient will vary linearly with incidence, because initially there is purely supersonic flow, but at a sufficient incidence the bow shock wave will detach, and there will be mixed flow: evidence suggests that, from then on, lift coefficient will vary with incidence to the power of about two-thirds. Fig. 5(*c*) shows what may be expected at the same Mach number, but for a moderate thickness/chord ratio. Initially the lift coefficient will

vary linearly with incidence, as before, because initially there will still be purely supersonic flow, but for this thickness/chord ratio the bow shock will detach at a fairly small incidence and there will be mixed flow; as the incidence can still be considered small compared with the thickness/chord ratio, the lift coefficient will continue to vary linearly with incidence, although not necessarily with the same slope as at zero incidence. Eventually, of course, the incidence will become large compared with the thickness/chord ratio, and so then the variation of lift coefficient with incidence to the power two-thirds may be expected to set in. Finally, Fig. 5(*d*) shows what may be expected when the thickness/chord ratio is further increased at the same Mach number. The bow shock will now be detached at zero incidence and there will be mixed flow at all incidences. Initially the incidence is small compared with the thickness/chord ratio, and the lift coefficient will vary linearly with incidence, but when the incidence becomes large compared with the thickness/chord ratio, the variation to the power two-thirds will be expected.

The similarity laws also indicate that one will probably have to revise one's ideas as to how lift-dependent drag should vary with lift. At subsonic and supersonic speeds one usually seeks a linear variation between the drag coefficient, C_{Di}, and the square of the lift coefficient, C_L. If however the lift coefficient is varying with the incidence, α, to the power two-thirds, then it is possible that C_{Di} will be proportional to $\alpha^{5/3}$, that is, proportional to $C_L^{5/2}$. In these circumstances it may be more convenient to compare C_{Di} with $C_L\alpha$. The relation between these two will, of course, be linear at subsonic and supersonic speeds, and may well be linear at transonic (mixed-flow) speeds over parts of the range. For example, there is evidence to suggest that for small incidences, when almost full theoretical leading edge suction is realised, C_{Di} is proportional to $C_L\alpha$, but that at large incidences increments in C_{Di} are equal to the increments in $C_L\alpha$, corresponding to the realisation of no further leading edge suction. In short, curves of C_{Di} against $C_L\alpha$ like those indicated in Fig. 6 may be expected in the mixed-flow régime of speeds.

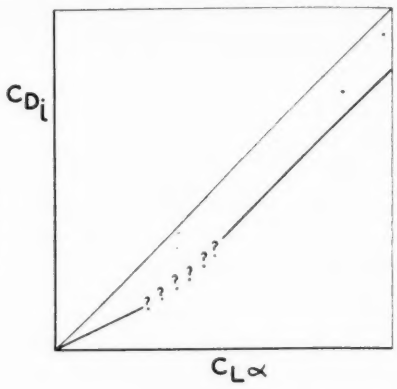

FIGURE 6. Variation of lift-dependent drag coefficient with incidence.

5. Solutions of the Transonic Small Perturbation Equations

The theory of small perturbation leads initially to the following partial differential equation for the velocity potential

$$(1-M_\infty^2)\,\phi_{xx}+\phi_{yy}+\phi_{zz}=0.$$

The use of this equation for subsonic and supersonic speeds can be justified *a posteriori*. One is naturally tempted to ask whether this equation can be justified at transonic speeds. The answer can be provided partly by investigating the limits to which the various forces, on a wing, say, tend as a Mach number of unity is approached from the subsonic and supersonic sides. In Fig. 7 are given, by way of example, the lift and zero-lift drag forces on a two-dimensional aerofoil, a rectangular wing, a triangular wing, and an untapered swept-back wing. We observe that the limits as the Mach number tends to unity may be either finite or infinite, but more significant is the fact that whereas the lift tends to the same limit from the two sides, the drag invariably tends to a different limit, being zero of course at subsonic speeds. These trends are typical of the antisymmetric or incidence problem and the symmetric or thickness problem, respectively. Thus for zero-lift drag something more refined in the transonic region is clearly necessary, but in the case of lifting, or antisymmetric, forces, the equivalence of the two limits, particularly when finite, gives some hope that the solutions in the transonic region may have some significance. The values for $M_\infty=1$ are particularly easy to obtain, for in this case the potential equation reduces to

$$\phi_{yy}+\phi_{zz}=0,$$

which merely involves solving the two-dimensional Laplace equation for the cross-flow. Following Jones[14] there has been extensive exploitation of this equation, in what has become known as 'slender wing, or body, theory', or alternatively 'sonic theory'.[15, 16, 17, 18, 19]

Turning now to transonic problems for which the linear potential equation is definitely inadequate, it can be shown that the equation which contains the essential non-linear term to cater for transonic problems is

$$\left(1-M_\infty^2-\frac{\gamma+1}{V_\infty}\,\phi_x\right)\phi_{xx}+\phi_{yy}+\phi_{zz}=0.$$

Such solutions[6, 20, 21, 22, 23, 24, 25, 26] as have been obtained of this non-linear transonic equation are all for two-dimensional flow. This is somewhat unfortunate in that the results are not therefore immediately applicable to aircraft design, but against this it was for two-dimensional flow that, as has been seen, the limiting solutions of the subsonic and supersonic equations were obviously most widely in error.

The problem of the flow past aerofoils of double-wedge section and of parabolic-arc section, at zero incidence and at small incidences, is now fairly well buttoned-up in the transonic region. The results are summarised in Fig. 8. It will be seen that the theoretical zero-lift drag is known throughout the Mach number range, but there are still one or two gaps in the curves of lift and aerodynamic centre position, notably in the

lower transonic range for aerofoils of double-wedge section. Before discussing the significance of some of these results, (*see* Section 7) it is instructive to examine the nature of the changes in the flow pattern that occur in the transonic region. Our knowledge of these changes has been greatly advanced by these theoretical studies.

6. Flow Patterns in the Transonic Region

Following Gullstrand[27] the transonic flow past a body can be described in terms of the following seven Mach numbers:

$M_\infty = M_{ml}$ below which the flow is entirely subsonic,
$M_\infty = M_{tl}$ below which the flow is shock-free,
$M_\infty = M_{sl}$ at which the stern shock-wave is just attached to the trailing edge,
$M_\infty = 1$ sonic speed,
$M_\infty = M_{su}$ at which the downwind-going Mach line from the intersection of the sonic line and the bow shock-wave intersects the trailing edge,
$M_\infty = M_{tu}$ at which the bow shock-wave is just attached to the leading edge,
$M_\infty = M_{mu}$ above which the flow is entirely supersonic.

The significance of these Mach numbers is that between M_{ml} and M_{mu} one has a mixed-flow problem, and between M_{sl} and M_{su} one has the so-called 'sonic range,' which will be defined below. The Mach numbers M_{tl} and M_{tu}, unlike the other pairs, are not related, but clearly the drag-rise is directly related to M_{tl}, and the final loss of leading-edge suction to M_{tu}. For round-nose aerofoils both M_{tu} and M_{mu} are infinite, and for aerofoils having a 'kink,' like the double-wedge, both M_{ml} and M_{tl} are zero.

The part that these Mach numbers play in describing the flow pattern can be appreciated by referring to Fig. 9, which shows in the upper series of pictures the flow pattern about a parabolic-arc aerofoil at zero incidence, and in the lower series of graphs the Mach number distribution over the aerofoil and the extensions of its chord. In the upper series of pictures solid lines represent shock waves, broken lines Mach lines and chain-dotted lines sonic lines. The flow patterns refer to a sequence of steady states: in accelerated motion they would be different, particularly near a Mach number of unity.

When the flow is entirely subsonic ($M_\infty < M_{ml}$) the

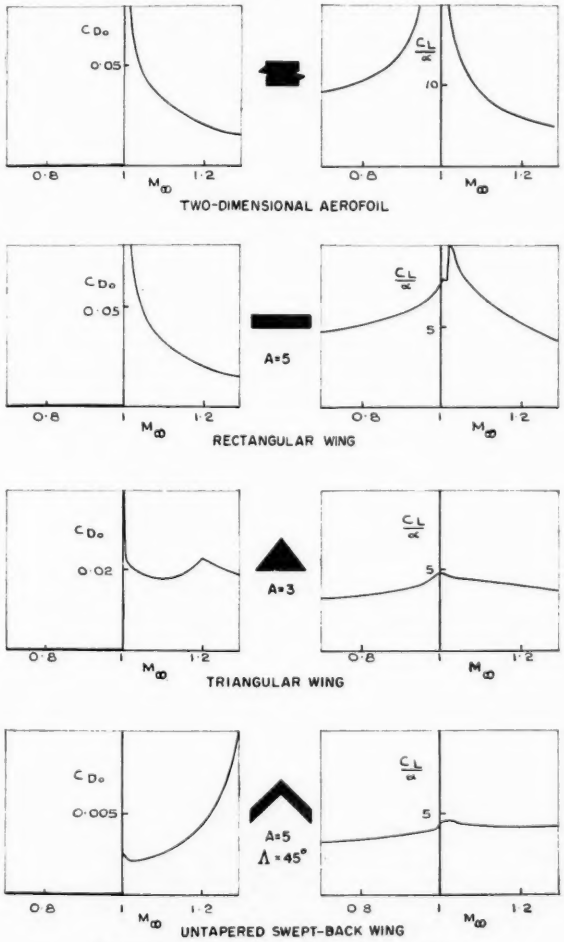

FIGURE 7. The predictions of linear theory. (Double-wedge section, $\tau = 0{\cdot}06$).

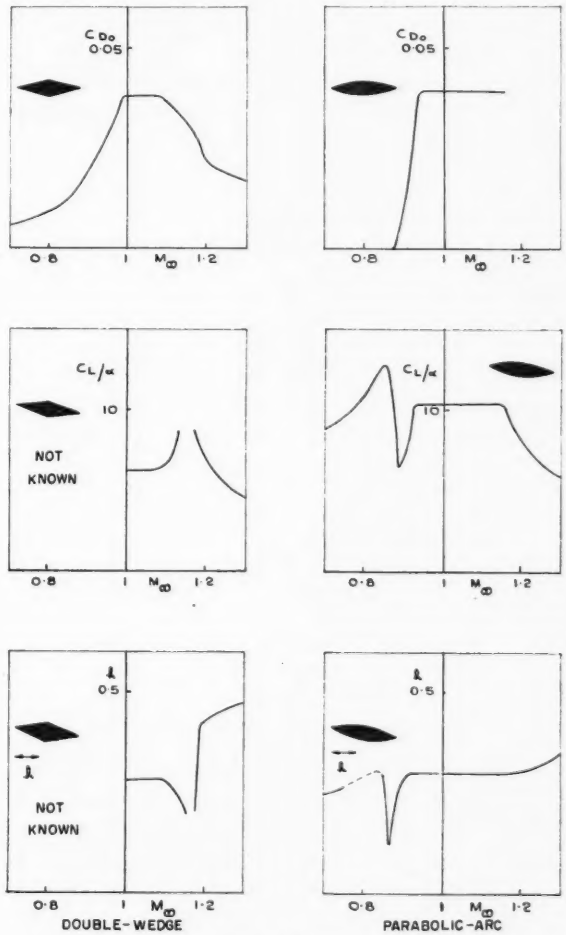

FIGURE 8. Theoretical forces on two aerofoils. ($\tau = 0{\cdot}06$).

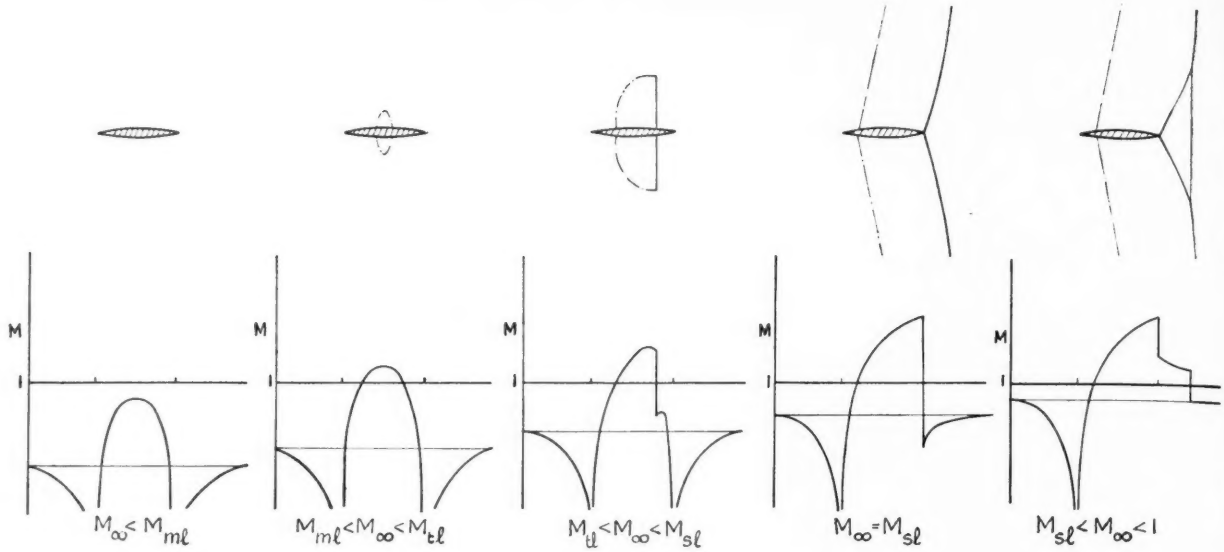

FIGURE 9. Flow patterns at transonic speeds.

flow pattern is, for this aerofoil, symmetrical about a line normal to the chord at its midpoint. When the Mach number is such that there is a small supersonic region around the point of maximum velocity, but the flow is still shock-free ($M_{m\ell} < M_\infty < M_{t\ell}$), the flow pattern is still symmetrical. At high Mach numbers ($M_{t\ell} < M_\infty < M_{s\ell}$) the supersonic region is terminated by a nearly normal shock-wave, which at a certain Mach number ($M_\infty = M_{s\ell}$) is just at the trailing edge. At Mach numbers still nearer unity ($M_{s\ell} < M_\infty < 1$) the trailing-edge shock-wave is oblique, and there is a stern shock-wave which takes up a position downstream of the aerofoil, and which moves to infinity as M_∞ tends to 1. The trailing-edge shock-wave is still joined to the sonic line at its outer extremity, which moves to infinity laterally as M_∞ tends to 1.

At Mach numbers just above unity ($M_{su} > M_\infty > 1$) there is a bow shock-wave ahead of the aerofoil; this shock-wave is an infinite distance upstream at $M_\infty = 1$. The sonic line runs into this bow shock-wave, the point of intersection being nearer to the aerofoil at the higher Mach numbers. At a certain Mach number ($M_\infty = M_{su}$) this point of intersection is such that the downwind-going Mach line from this point intersects the trailing edge. This implies that at Mach numbers higher than M_{su}, the presence of the supersonic region ahead of the bow wave makes its presence known to the aerofoil 'around the outermost tips of the subsonic region.' At some other Mach number ($M_\infty = M_{tu}$), which in most cases will be greater than M_{su}, the bow shock-wave is just attached to the leading edge, and above some higher Mach number ($M_\infty = M_{mu}$) the flow is entirely supersonic.

The distributions of Mach number on the aerofoil for various main stream Mach numbers M_∞ show that there is no variation of the local Mach number M with M_∞ in the range $M_{s\ell} < M_\infty < M_{su}$, as can be seen more clearly in the cross-plot shown in Fig. 10. Mathematically this result may be written

$$\left(\frac{dM}{dM_\infty}\right)_{M_\infty = 1} = 0.$$

This result is a consequence of transonic theory: that it is plausible can be appreciated from the following simple argument. At a slightly supersonic Mach number $M_\infty = 1 + \delta$ the Mach number behind the bow wave, assumed normal, will be roughly $1 - \delta$, and so, provided the bow wave is not too close to the body, the flow pattern, and hence the distribution of Mach number, will be roughly the same as at the slightly subsonic Mach number $M_\infty = 1 - \delta$. Thus M will be stationary through $M_\infty = 1$, and hence in the transonic range it is simpler, as well as more illuminating, to consider distributions of local Mach number rather than distributions of pressure coefficient. Actually the local Mach number is stationary over a larger range than small perturbation theory could predict. Maccoll[28] was the first to point out that in the transonic range the ratio of the static pressure on a bluff forebody to the total pressure behind a normal shock-wave is independent of main stream Mach number, which is tantamount to saying that the local Mach number does not vary.

From this result it can easily be shown[6] that the exact variation of the pressure coefficient at a point, if we assume inviscid flow, is given by

$$\left(\frac{dC_p}{dM_\infty}\right)_{M_\infty = 1} = \frac{4}{\gamma + 1} - \frac{2}{\gamma + 1}(C_p)_{M_\infty = 1}$$

From this we can deduce that the exact variation of drag coefficient*, lift coefficient, aerodynamic centre position,

*It is assumed here that the body is "complete": *e.g.* the results do not apply to a forebody on its own.

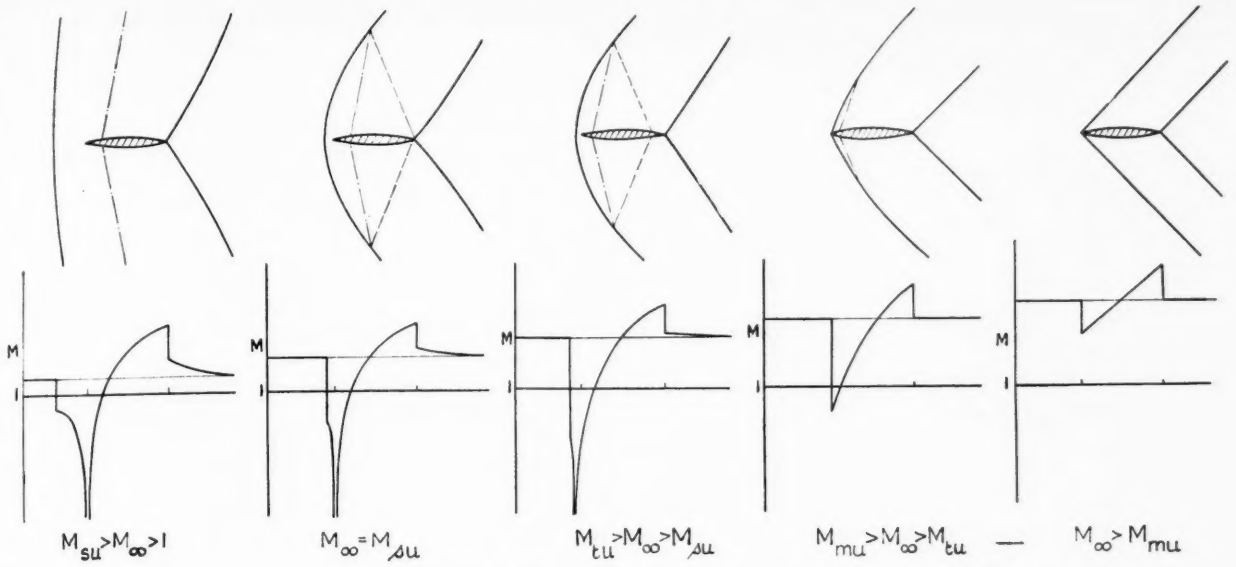

FIGURE 9. Flow patterns at transonic speeds.

for example, are given by

$$\left(\frac{d\,C_D}{d\,M_\infty}\right)_{M_\infty=1} = -\frac{2}{\gamma+1}(C_D)_{M_\infty=1}$$

$$\left(\frac{d\,(C_L/\alpha)}{d\,M_\infty}\right)_{M_\infty=1} = -\frac{2}{\gamma+1}\left(\frac{C_L}{\alpha}\right)_{M_\infty=1}$$

$$\left(\frac{d\,h}{d\,M_\infty}\right)_{M_\infty=1} = 0.$$

These results are of value when one has to draw curves through meagre data in the transonic region.

The flow patterns just discussed have been for aerofoils, but similar results would be expected for bodies of revolution and, with some modifications perhaps, for general three-dimensional bodies. In particular, Mach numbers analogous to those introduced at the beginning of this section play an important part in estimating pressure distributions at transonic speeds.

7. Features of Transonic Air Flow of Importance in Aircraft Design

Let us now discuss the significance of the small perturbation theoretical results for two-dimensional aerofoils which were referred to in Section 5, (*see* Fig. 8), for they bring out certain points of fundamental importance in aircraft design. They also have a bearing on the limitations of transonic small-perturbation theory. It is known that an aircraft that has to fly at a range of speeds from subsonic to supersonic will experience some change in its aerodynamic characteristics on passing through the speed of sound: it will, for example, experience an increase in drag coefficient, and it will also experience an overall rearward movement in aerodynamic centre. One of the aims in aircraft design is to minimise these changes, and something can be done in this respect. The use of thin wings will reduce the increase in drag coefficient, and the use of wings of low aspect ratio will reduce the rearward movement of the aerodynamic centre. Some residual changes will remain, and these are accepted. Of more importance is to ensure that the inevitable changes in the transonic region shall be gradual, for violent changes can seriously

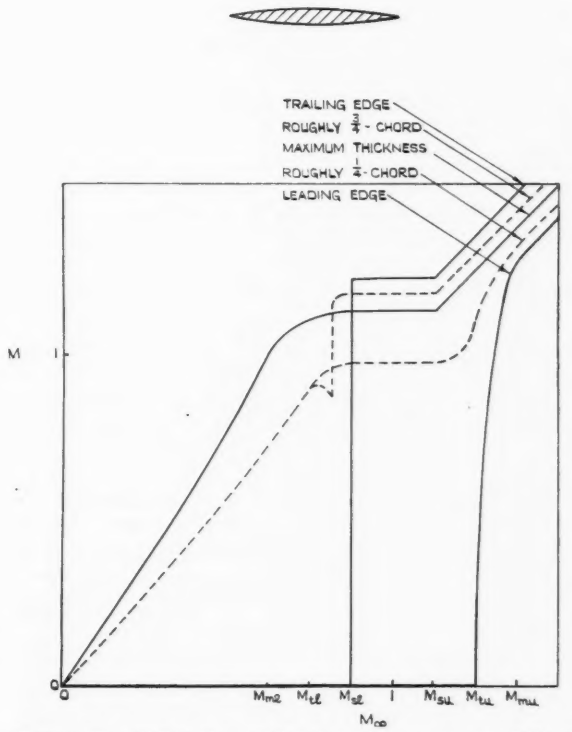

FIGURE 10. Distribution of Mach number on an aerofoil of parabolic-arc section.

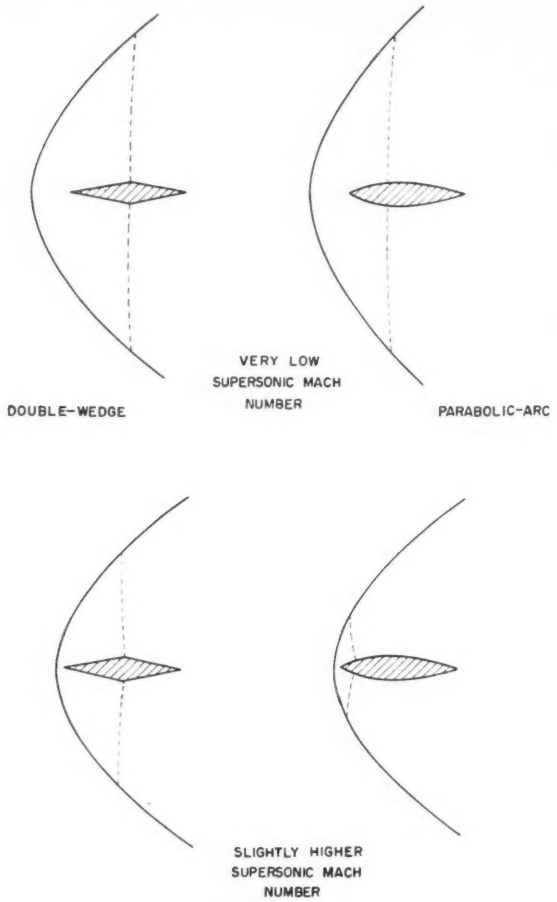

FIGURE 11. Flow fields in the upper transonic region.

affect the stability and manoeuvrability of an aircraft; this lessens its value as a military aircraft, if it does not actually make it dangerous to fly. This leads us to the very heart of the transonic problem. At transonic speeds, more precisely mixed-flow speeds, there will be regions of both subsonic and supersonic local speed on the wing or body, separated by a sonic line where the flow is accelerating locally, and by a shock wave where it is decelerating. The fundamental transonic problem is concerned with the manner in which these sonic lines and shock waves move on the body as the main stream speed changes from subsonic to supersonic, or vice versa.

In the next two sections interesting features of the theoretical results from this point of view will be considered. For definiteness an increase in speed from subsonic to supersonic will be assumed.

8. Sonic Line Movements

Interesting features in Fig. 8 from the viewpoint of aircraft design are the violent changes in lift and aerodynamic centre position that are predicted in the upper transonic region with the double-wedge section, compared with the almost completely smooth characteristics of the parabolic-arc aerofoil. The differences have recently been checked experimentally,[29] and are predominantly an inviscid flow effect. They are associated with the different ways in which the sonic lines are encouraged to move forward on the aerofoil. As shown in Fig. 11, at low supersonic speeds the fields of flow about the double-wedge aerofoil and the parabolic-arc aerofoil are similar, the main feature in the present context being an embedded region of subsonic flow bounded at the front by the detached bow shock wave, and at the rear by the sonic line. With increase of main stream Mach number the bow wave moves backwards towards the aerofoil, and, with the parabolic-arc section, the sonic line moves forward to meet it. With the double-wedge section, however, the sonic line is anchored to the kink at maximum thickness, and it is likely that it does not move forward until the bow shock wave is attached. Because of this the embedded subsonic region with the double-wedge aerofoil is forced to collapse more suddenly, and it is not surprising that this sudden collapse, which occurs in that small range of Mach number between shock attachment and the establishment of fully supersonic flow, should lead to somewhat violent changes in the lift and aerodynamic centre characteristics. These peculiar results of the double-wedge section do not, however, present a serious design problem. The indications are that with an aerofoil of smooth profile, such as most aeroplanes possess, the sonic line will move forward in an orderly manner without causing any violent changes in aerodynamic characteristics. There might be some cause for anxiety with guided missiles, which for reasons of manufacture often have wings of wedge-like profile; but then missiles often do not descend to the transonic region.

9. Shock Wave Movements

The other important features exhibited in Fig. 8 are the violent changes that occur in the lower transonic region. These are associated with shock wave movements. Fig. 12 shows the results of some tests on three two-dimensional aerofoils which all exhibit similar characteristics to those predicted theoretically (*see* Fig. 8). It will be noted, however, that flow separation (indicated by 'filled-in' symbols) was observed in all cases in the critical region. In the movement of shock waves, therefore, the viscosity of the fluid plays an important role, for on nearly all aerofoils the shock waves cause separation of the boundary layer at some stage in their movement rearwards. Thus account must be taken of the boundary layer in assessing the movement of shock waves, and its effect on aircraft design.

A paper on this subject was recently read before the Society,[30] and accordingly it is not proposed to discuss this problem further here. It suffices to say that shock-induced flow separation is likely to remain a problem at high incidences, and work will certainly be required to obtain a full understanding of it, its effects, and ways of alleviating it. But equally there are indications that there will be circumstances in which flow separation will

not occur, and then there will be interest in the separation-free characteristics. It is here that transonic small-perturbation theory will play a useful part in design. The recent work at the National Physical Laboratory on shock-induced flow separation will be of value in establishing the circumstances under which such theory can be expected to give valid results.

10. Conclusions

It is hoped that this paper has helped to show that the transonic region is not the mysterious region that it was thought some ten years ago. It is clear that in many respects the inner part of the transonic region, what is now called the sonic region, including Mach number one itself, presents a simpler flow problem than either subsonic or supersonic flow. The really tricky regions are those between the subsonic régime and the sonic régime, and between the sonic régime and the supersonic régime. The former, in which there are shock waves on the surface of the body, is the most difficult region, and, as has been shown, cannot be considered from an inviscid point of view alone. In the latter, one is concerned with bow shock attachment, but the indications are that this region need not lead to particularly troublesome design problems.

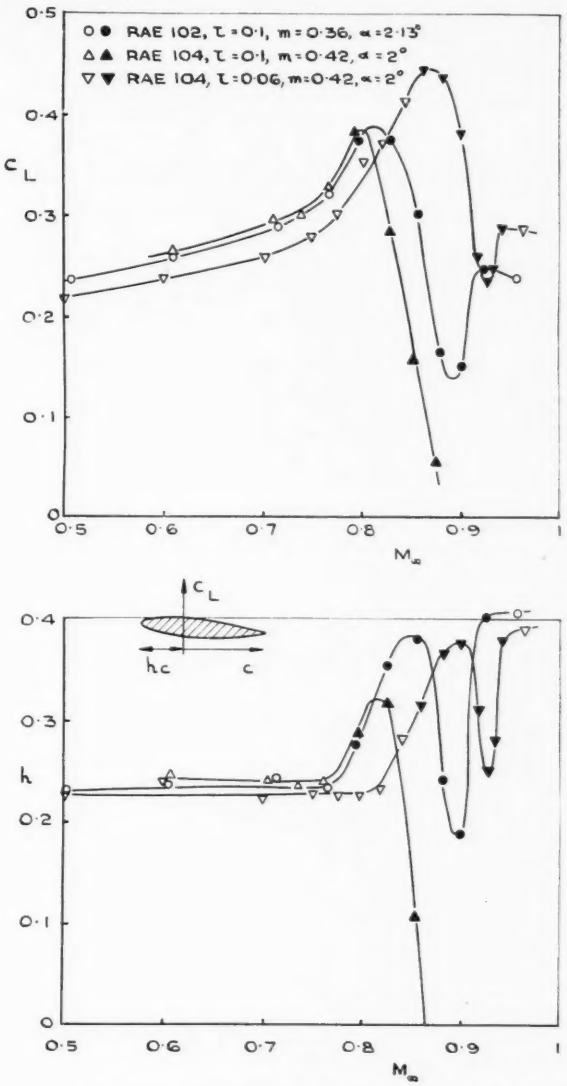

FIGURE 12. Measured forces on three aerofoils. ($R = 1{\cdot}8$ million. Filled-in symbols denote that flow separation was observed).

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Ninety-first Annual Report of the Council

1955-1956

FOR the first time for many years the Society was given a Presidential Address. It was delivered on the 90th Anniversary of the foundation of the Society. The President spoke of the past, the present, and the future.

In his remarks concerning the future he stressed two outstanding needs—the need for more members and the need for a new home for the Royal Aeronautical Society. These can only be attained through the enthusiasm and endeavour of not only the President and the Council, but by the zealous efforts of each individual member of the Society.

A pamphlet regarding membership has been prepared and distributed throughout the industry and the schools and colleges, and it has already shown some results.

A Year Book and List of Members—the first since 1947—has been sent to all members of the Society, and has been well received, for it has proved both interesting and useful.

The Council for the year 1955-1956 is as follows:-

PRESIDENT

N. E. ROWE, C.B.E., B.SC., F.C.G.I., M.I.MECH.E., F.I.A.S., F.R.AE.S.

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MR. B. P. LAIGHT
MR. P. A. HEARNE

**Not a Member of the Council of the Royal Aeronautical Society*

Representatives on Other Bodies

General Board of the National Physical Laboratory: Sir William Farren and Major G. P. Bulman.
Executive Board of the National Physical Laboratory: Sir William Farren.
Royal Society—National Committee for Theoretical and Applied Mechanics: Professor W. J. Duncan.
Institution of Electrical Engineers—Committee on Regulations for the Electrical Equipment of Aircraft: Mr. C. G. A. Woodford.
Institution of Electrical Engineers—Committee on Radio Equipment for Civil Aircraft: Mr. C. H. Jackson.
Institution of Mechanical Engineers—National Certificates

and Diplomas in Mechanical Engineering: Mr. R. Tatham.

Governing Body of the College of Technology, Loughborough: Mr. A. G. Elliott.

Royal Aircraft Establishment Technical College Advisory Board: Sir William Farren (*Chairman*) and Professor A. R. Collar.

Board of Governors of the College of Aeronautics: Sir Roy Fedden and Sir Harold Roxbee Cox.

British Standards Institution—Aeronautical Glossary Committee: Sir Leonard Bairstow.

British Standards Institution—Units and Symbols Standards Committee: Dr. A. M. Ballantyne.

British Standards Institution—Aircraft Industry Standards Committee: Mr. F. M. Owner and Mr. H. Knowler.

British Standards Institution—Technical Committee MEE/143—Gas Turbines: Mr. F. M. Owner.

British Standards Institution—Co-ordination of Definitions Units (USM/1): Sir Sydney Camm.

British Standards Institution—Abbreviations and Symbols Committee (USM/2): Miss E. C. Pike.

Ministry of Education—Board of Studies in Engineering: Professor A. R. Collar.

Segrave Trophy Committee: Major R. H. Mayo.

City and Guilds of London Institute—Advisory Committee on Aeronautical Engineering Practice: Dr. A. M. Ballantyne, Sir Roy Fedden, Mr. B. S. Shenstone and Sir Harry Garner.

Association of Special Libraries and Information Bureaux: Captain J. L. Pritchard.

National Central Library: Captain J. L. Pritchard.

Regional Advisory Committee for Mechanical Engineering: Sir John S. Buchanan.

University of London Senate—Board of Studies in Aeronautical Engineering: Dr. A. M. Ballantyne.

Royal Technical College, Salford—Engineering Advisory Committee: Mr. J. R. Ewans. (Mr. S. D. Davies was the representative until March 1956.)

Court of the University of Bristol: Dr. A. E. Russell.

University of Cambridge Local Examinations Syndicate—Joint Committee: Dr. A. M. Ballantyne.

Professional Classes Aid Council: Dr. A. M. Ballantyne.

Election of President and Vice-Presidents

Mr. N. E. Rowe, C.B.E., B.Sc., F.C.G.I., F.I.A.S., F.R.Ae.S., was elected President for 1955/56 and took office at the Ninetieth Annual General Meeting held on 5th May 1955.

At the Meeting of Council held on 9th June 1955 the following were elected Vice-Presidents:

Mr. G. R. Edwards, C.B.E., B.Sc., F.R.Ae.S.

Mr. E. T. Jones, C.B., O.B.E., M.Eng., F.R.Ae.S.

Mr. P. G. Masefield, M.A., Hon.F.I.A.S., F.R.Ae.S.

At the Meeting of Council held on 28th September 1955 Mr. E. T. Jones, C.B., O.B.E., M.Eng., F.R.Ae.S., was elected President-Elect of the Society.

Fellowship of the Society

At the Ninetieth Annual General Meeting, held on 5th May 1955, it was announced that the following had been elected Fellows:

Dr. J. H. Argyris	W. M. Evans	Sir Arthur de T. Nevill
Dr. K. G. Bergin	J. C. Floyd	Dr. J. H. Preston
G. B. Belt	Sir Wilmot Hudson Fysh	T. Simpson
Air Marshal Sir John Boothman	E. A. Gibson	Sir Lawrence J. Wackett
Dr. N. A. de Bruyne	Dr. G. S. Hislop	J. L. Watkins
H. W. Clarke	D. James	F. L. Wattendorf
E. J. Earnshaw	J. C. Kelly-Rogers	D. H. Williams
	P. McCormack	

Lectures

The following Main Lectures and Section Lectures have been read before the Society in 1955/56:

1955

6th October: MAIN LECTURE—The Eleventh British Commonwealth and Empire Lecture—"The Growth of Aeronautical Research in Canada during the Post-War Decade," Dr. J. J. Green, M.B.E., B.Sc., A.R.C.S., D.I.C., F.I.A.S., F.C.A.I., F.R.Ae.S.

20th October: MAIN LECTURE—The Jet Flap, I. M. Davidson, B.Sc.(Eng.), A.F.R.Ae.S.

25th October: SECTION LECTURE—Boundary Layer Effects in Supersonic Flow, R. J. Monaghan, M.A., A.F.R.Ae.S.

8th November: SECTION LECTURE—High Aspect Ratio Wings, M. Hurel.

10th November: MAIN LECTURE AT MERTHYR TYDFIL BRANCH—A Review of some Combustion problems Associated with the Aero Gas Turbine, Dr. J. S. Clarke, O.B.E., F.R.Ae.S.

15th November: SECTION LECTURE—The Planning of Experiments, Sir Ronald A. Fisher, Sc.D., F.R.S.

17th November: ALL DAY SECTION LECTURE on Aircraft Design Philosophy—Structural Testing, Dr. P. B. Walker, C.B.E., M.A., F.R.Ae.S.; Fatigue, H. Giddings, A.F.R.Ae.S.; Flight Loads, R. H. Sandifer, F.R.Ae.S.; Safety Factors, J. K. Williams, B.Sc., A.F.R.Ae.S.

22nd November: SECTION LECTURE—Aviation Journalism, Charles Gardner, O.B.E., A.R.Ae.S.

29th November: SECTION LECTURE—The Noise of Jet Engines, F. B. Greatrex, B.A., A.F.R.Ae.S.

1st December: MAIN LECTURE AT BOSCOMBE DOWN BRANCH—Free Flight Techniques for High Speed Aerodynamics Research, J. A. Hamilton, M.B.E., B.Sc., A.F.R.Ae.S. and P. A. Hufton, M.Sc.

6th December: SECTION LECTURE—Fatigue Aspects of Structural Design, W. A. P. Fisher, B.A., A.M.I.Mech.E.

16th December: SECTION LECTURE—A Lecture on Airships, Lord Ventry, *Companion*.

20th December: SECTION LECTURE—Recent Advances in Aircraft Adhesives, Dr. N. A. de Bruyne, M.A., F.R.Ae.S.

1956

5th January: MAIN LECTURE—Young People's Lecture, Test Flying—Current Problems and Techniques, Wing Commander R. P. Beamont, O.B.E., D.S.O., D.F.C., A.R.Ae.S.

10th January: SECTION LECTURE—Some Modern Structural Problems, Professor W. S. Hemp, M.A., F.R.Ae.S.

12 January: PRESIDENTIAL ADDRESS—N. E. Rowe, C.B.E., B.Sc., F.C.G.I., F.R.Ae.S., F.I.A.S.

17th January: SECTION LECTURE—Crack Detection in Aircraft Structures, Dr. W. Deck.

24th January: SECTION LECTURE—Low Consumption Jet Engines, A. A. Lombard, F.R.Ae.S.

2nd February: SECTION LECTURE—New Ideas in Plastics for Aircraft Structures, J. E. Gordon, B.Sc.

9th February: SECTION LECTURE—Propellers for Military and Civil Aircraft, L. G. Fairhurst, M.I.Mech.E., F.R.Ae.S.

16th February: MAIN LECTURE AT YEOVIL BRANCH—The First Stringfellow Memorial Lecture, "The Lives and Work of William Samuel Henson and John Stringfellow," Dr. A. M. Ballantyne, T.D., B.Sc., A.F.I.A.S., Hon.F.C.A.I., A.F.R.Ae.S. and Captain J. L. Pritchard, C.B.E., Hon.F.I.A.S., Hon. F.R.Ae.S.

21st February: SECTION LECTURE—Design of Low Landing Speed Aircraft, R. C. McIntyre, A.F.R.Ae.S.

28th February: SECTION LECTURE—Use of Elementary Plasticity in Design, A. J. Barrett, B.Sc.(Eng.), M.S. in A.E., M.I.A.S., A.F.R.Ae.S.

1st March: SECTION LECTURE—Power Plants for Supersonic Flight, Dr. E. S. Moult, B.Sc., M.I.Mech.E., F.R.Ae.S.

7th March: MAIN LECTURE—The Ninth Louis Bleriot Lecture—in Paris, A Philosophy of Aeronautical Research, E. T. Jones, C.B., O.B.E., M.Eng., F.R.Ae.S.

15th March: MAIN LECTURE—The High Temperature Turbo-Jet Engine, D. G. Ainley, A.F.R.Ae.S.

20th March: SECTION LECTURE—Experiments on Flow Over Swept Back Wings, P. T. Fink, B.E., A.F.R.Ae.S.

21st March: MAIN LECTURE AT MANCHESTER BRANCH—The First Chadwick Memorial Lecture, The Life and Work of Roy Chadwick, H. Rogerson, M.B.E., F.R.Ae.S.

The following Lectures will complete the Programme:

5th April: MAIN LECTURE AT BELFAST BRANCH—Problems Associated with the Production and Use of Wrought Aluminium Alloys, G. Forrest, B.Sc.(Eng.), A.F.R.Ae.S. and K. Gunn.

12th April: SECTION DISCUSSION—Aircraft Interior Lay-out, led by an: Operator, R. C. Morgan; Pilot, Captain O. P. Jones; Passenger, C. F. Holloway; Designer, D. P. Thorne; Stewardess, Miss D. Furness.

17th April: SECTION LECTURE—Investigation of Aircraft Accidents, E. L. Ripley, O.B.E., B.Sc., A.R.C.S., D.I.C., A.F.R.Ae.S.

19th April: MAIN LECTURE—High Speed Experimental Test Flying, Lt.-Col. Charles E. Yeager, U.S.A.F.

24th April: SECTION LECTURE—The Development of Helicopter Transport—R. H. Whitby, B.Sc., A.R.C.S., D.I.C., A.F.R.Ae.S.

9th May: ALL DAY SECTION LECTURE ON SUPERSONIC FLIGHT—Propulsion, A. V. Cleaver, F.R.Ae.S.; Aerodynamics, P. J. Duncton, B.Sc., D.I.C., A.F.R.Ae.S.; Structures, D. J. Farrar, M.A., A.F.R.Ae.S.; Cabin Conditions, Control, etc., H. H. Gardner, B.Sc., F.R.Ae.S.

15th May: SECTION LECTURE—Medical Aspects of Flight Comfort and Efficiency, Dr. A. Buchanan Barbour, O.B.E., M.R.C.S., L.R.C.P., F.R.Ae.S.

17th May: MAIN LECTURE—The 44th Wilbur Wright Memorial Lecture, Sir William S. Farren, C.B., M.B.E., F.R.S., F.R.Ae.S.

Divisions

During the year the Southern African Division have elected for the first time Honorary Officers, and the first Honorary President is the Hon. J. H. Viljoen, Minister for Education, Arts and Science in the Union Government. Colonel Sir T. Ellis Robins, Director of the British South African Company and Central African Airways, and Mr. D. H. Yates-Smith have become Honorary Vice-Presidents. Professor W. J. Walker has replaced Dr. R. Cheetham as President of the Division.

In the New Zealand Division Air Commodore G. Carter has succeeded Mr. C. W. Labette as President.

The Australian Division has founded a third Branch at Salisbury.

During November 1955 the Commonwealth Advisory Aeronautical Research Council met in Australia, and the Delegates from the United Kingdom consisted of Mr. E. T. Jones (President-Elect), Professor Duncan (Member of Council), Professor E. J. Richards and Mr. M. B. Morgan. These Delegates arranged to give some lectures and received the hospitality of the Division through the Branches. Professor Richards came home via Johannesburg, but unfortunately he was unable to meet many of the Division, for it was the holiday season.

Many Members of the Divisions have been visitors to London, and all called at 4 Hamilton Place. Dr. Shaw (Australia), Mr. Coleridge (the New Zealand Secretary), Air Commodore Carter (President of the New Zealand Division), Mr. Labette (Past President, New Zealand) and Mr. Nicholson (Vice-President, Southern Africa Division) all spent some time with the Secretary, who was pleased to see once more some of those who had made his visit to the Divisions so enjoyable and memorable.

Many of these visitors attended the Commonwealth and British Empire Lecture by Dr. Green, and attended the Dinner afterwards. All the Divisions were represented, for Sir W. Hudson Fysh was able to come and represent the Australian Division. The Council welcomed the visitors and were pleased to learn at first hand of the work of the Divisions.

Dr. J. J. Green, in presenting the British Commonwealth and Empire Lecture, was the first member of the Canadian Aeronautical Institute to read a paper before the Society.

The Council appreciates the endeavours of the Divisional Councils and their Branch Committees, and would wish to welcome the Division members whenever they visit the United Kingdom.

Branches

During the past year a new Branch has been formed at Christchurch, Hants, but the Branch at Portsmouth unfortunately has had to be closed through lack of support, so the total number of Branches remains 25.

Three Memorial Lectures have been inaugurated—the Henson and Stringfellow Memorial Lecture at the Yeovill Branch, the Chadwick Memorial Lecture at the Manchester Branch and the Pilcher Memorial Lecture at the Glasgow Branch. Main Lectures have been held also at the Merthyr Tydfil, Boscombe Down and Belfast Branches. These lectures are invariably well attended, for the Branch Secretaries are enthusiastic, and transfer their enthusiasm to the members. The Lecture at Yeovil was attended by more than 300 people. An excellent feature of the Main Lectures which are held at Branches is the ready support given by the neighbouring Branches, as witnessed by the coach loads which come no little distance in many cases.

The Branches Conference held biannually at the Society continues to provide a meeting place for Branch Chairmen and Secretaries and Committee Members to exchange views and ideas.

The Annual Reports of the individual Branches show a wide range of interest and enterprise and it has been a most successful year. The local Branch Committees, and particularly the Branch Secretaries, well deserve the congratulations of Council.

Many Branches are given assistance by firms with which they are associated; this is realised and appreciated by Council, who wish to give them their sincere thanks.

When he became President of the Society, Mr. N. E. Rowe gave up the Chairmanship of the Branches Committee, in which capacity he had served since 1946. To commemorate these years of service, he was presented with a silver tray, generously subscribed for by the Branches themselves, and inscribed with their names.

Membership

There has been a steady increase in Membership over the year; and this is shown in the Table on page 257. Although it is not apparent from the figures many new members to the Society have been in the lower grades, and not as would seem in the Associate Fellow grade, for there has been a continual transference of Student to

Graduate and Graduate and Associate to Associate Fellow. This means that the number of new Students and Graduates is much more than the indicated increases of 41 and 7. That the numbers of Graduates and Students continue to increase is a healthy sign, for it indicates that the more youthful members of the aeronautical profession are taking an interest in their professional Society.

Graduates' and Students' Section

During the year the interest of the Graduates and Students in the activities of the Section has increased noticeably. This is reflected not in the actual attendance figures at lectures and visits but in the more intangible quantity of the variety of members who attend these functions.

The year's lectures were once more on the lines of broad aspects of aviation rather than specialised subjects. The policy of inviting 50 per cent. of the lecturers from Graduates and Students and 50 per cent. from prominent personalities in their branch of the profession has been followed as far as possible. Unfortunately this aim was somewhat spoiled since one lecture by a Graduate was cancelled due to illness and in another case the Graduate was subsequently regraded an Associate Fellow!

It will be seen from the list of lecture meetings that there was a very catholic selection of subjects and that there was a distinct bias towards recent developments in aeronautics which are often subject to security. The Committee feel that lectures on these subjects form a very useful part in the training of the young aeronautical engineer who often has difficulty in acquiring the necessary background for his professional work.

The average lecture attendance in 1956 has been 61 which though appreciably higher than in 1953 and 1954, is slightly below last year's average of 65.

The success of the visits programme can be judged by the fact that almost every visit was over-subscribed. Since the number of visitors permitted varied with each visit, the mere quotation of the average number of persons attending has little meaning unless it is realised that this was usually 100 per cent. of the permitted number of visitors. Visits were made to firms, M. of S. Establishments, Airline bases and also to a wine cellar. All the hosts took a great deal of trouble to make the visits a success and the Committee is very grateful to them.

This year's dance, held on 29th October, was attended by 140 people and was honoured by the presence of the President and Mrs. Rowe. The promise of previous years was realised and the occasion was undoubtedly the most successful yet held. In view of this success, the Committee now intend to hold a complementary informal dance and party in the summer months.

The question of Society membership is one that has occupied the Committee in the past year. It has come increasingly to our attention that there are a large number of members or intending members of the aeronautical profession who are not members of the Society. Accordingly the Section has prepared drafts of leaflets setting out the principles and advantages of Society membership which it has submitted to the Secretary who has since included them in his recent pamphlet on these lines.

In addition, the Committee has attempted to arouse as much interest as possible among Graduates and Students in the Section's activities by means of pamphlets and questionnaires on lines of Section activities. The Committee has been greatly helped by the recent " grant " of a monthly page in the JOURNAL which it feels will materially aid it in the task of " keeping in touch " with the Section members.

The Committee feels that a considerable influx in younger members would occur if a drive for membership were launched through apprentice supervisors, colleges and universities and it is currently considering this matter.

The Council wish to thank the Committee for their work especially for their drive towards increased interest and membership, and would join the Section Committee in thanking all those who have contributed to the success of the past year.

LIST OF LECTURE MEETINGS DURING 1955-56

1955

29th March: Atomic Energy by Professor Rotblat, Ph.D., D.Sc., F.Inst.P.

14th April: Radio Aids to Navigation and Blind Landing by Captain F. Ormonroyd, M.A., B.E.A.

4th May: Structural and Aerodynamic Aspects of Supersonic Aircraft Design by E. J. Catchpole, B.Sc., M.S. in A.E., Grad.R.Ae.S. and W. J. Eggington, B.Sc., Grad.R.Ae.S.

4th October: Informal Talk on Aircraft Fatigue by Dr. P. B. Walker, C.B.E., M.A., Ph.D., F.R.Ae.S.

19th October: Film show on High Altitude Rocket Research and Guided Weapons.

17th November: The Supersonic Fighter by J. Fozard, B.Sc., D.C.Ae., A.F.R.Ae.S.

1st December: Aeroelasticity by H. Liner. Cancelled.

14th December: The Domain of the Helicopter by R. Hafner, Dip.Ing., F.R.Ae.S.

1956

31st January: An Introduction to Kinetic Heating by J. B. Edwards, B.Sc., Grad.R.Ae.S.

MEMBERSHIP AT 31st DECEMBER 1955

Grade	London Register		Australian Division		New Zealand Division		Southern Africa Division		Life and Honorary		Totals		Suspended London Register Members (included in the foregoing figures)	
Fellows	374	(370)	14	(10)	3	(—)	1	(1)	49	(52)	441	(433)	1	(6)
Associate Fellows	3,410	(3,193)	121	(114)	29	(29)	51	(42)	17	(17)	3,628	(3,395)	61	(71)
Associates	1,907	(1,934)	66	(69)	57	(59)	76	(76)	5	(5)	2,111	(2,143)	74	(107)
Graduates	1,217	(1,213)	61	(60)	8	(6)	5	(5)	—	(—)	1,291	(1,284)	35	(42)
Students	781	(737)	40	(45)	6	(5)	10	(9)	—	(—)	837	(796)	64	(46)
Founder Members	13	(14)	—	(—)	—	(—)	—	(—)	1	(1)	14	(15)	—	(—)
Companions	151	(149)	7	(7)	4	(4)	5	(4)	10	(10)	177	(174)	4	(6)
Temporary Honorary Members	—	(—)	—	(—)	—	(—)	—	(—)	51	(48)	51	(48)	—	(—)
	7,853	(7,610)	309	(305)	107	(103)	148	(137)	133	(133)	8,550	(8,288)	239	(278)

Figures in brackets are corresponding figures at 31st December 1954

14th February: Flight Testing of High Speed Aircraft by T. H. Kerr, B.Sc., A.F.R.Ae.S.
6th March: Annual General Meeting and Film Show.
28th March: Artificial Space Satellites by A. V. Cleaver, F.R.Ae.S.
18th April: Gas Turbines—Propeller or Jet? by R. M. Fitzgerald.

LIST OF VISITS DURING 1955-6

1955

30th April: Vickers-Armstrongs, Weybridge.
21st May: Hawker Aircraft, Kingston.
20th July: National Gas Turbine Establishment, Pyestock.
12th October: National Aeronautical Establishment, Bedford.
19th November: London Airport, M.T.C.A. buildings and B.E.A. Maintenance Base.
10th December: B.O.A.C. Flight Simulators, Meadowbank.

1956

18th January: Wine Cellar of H. Sichel & Son Ltd.
22nd February: de Havilland Engine Co. Ltd., Leavesden.
17th March: Fairey Aviation Co. Ltd., Hayes.
7th April: R.A.F., West Malling.
19th May: U.S. Third Air Force, Manston.

Honours Awarded to Members

Members of the Society have been honoured by Her Majesty the Queen during the year. These the Council have much pleasure in congratulating.

Other Honours have been conferred upon Members of the Society by learned Societies and other bodies; the Council also congratulates these recipients.

BIRTHDAY HONOURS LIST 1955

Commander of the Bath—G. W. H. Gardner (*Fellow*).

Commander of the Order of the British Empire—
Dr. P. B. Walker (*Fellow*).

NEW YEAR HONOURS LIST 1956

Knights Bachelor—Professor A. G. Pugsley (*Fellow*).

Commander of the Order of the British Empire—
Air Vice-Marshal A. C. Kermode (*Fellow*).
Mr. R. Graham (*Fellow*).
Mr. R. S. Stafford (*Fellow*).

Officer of the Order of the British Empire—
Wing Commander R. C. Fordham (*Associate Fellow*).
Wing Commander P. H. Legg (*Associate Fellow*).
Acting Wing Commander N. MacMillan (*Associate Fellow*).
Mr. G. A. V. Tyson (*Associate Fellow*).

Member of the Order of the British Empire—
Squadron Leader M. Hermiston (*Associate Fellow*).
Flight Lieutenant G. B. Tyler (*Graduate*)
Mr. A. J. A. Armstrong (*Associate*).
Group Captain G. Thripp (*Associate Fellow*).

THE CITY AND GUILDS OF LONDON INSTITUTE

Dr. L. Aitchison (*Fellow*) has been given the Insignia Award in Technology by the City and Guilds of London Institute, for his work in Metallurgy.

Mr. N. E. Rowe (*Fellow*) has been presented with a Diploma of Fellowship of the City and Guilds of London Institute.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

James H. Doolittle (*Fellow*) has been elected an Honorary Member of the American Society of Mechanical Engineers.

FEDERATION AERONAUTIQUE INTERNATIONALE

Mr. Philip Wills (*Associate Fellow*) has been awarded the Lilienthal Medal for 1954, and also the Paul Tissandier Diploma. This diploma is awarded to those who have "by their influence, work, initiative and devotion, or in some other way, served the cause of aviation in general, especially private and sporting flying."

SMITHSONIAN INSTITUTION

Dr. Jerome C. Hunsaker (*Honorary Fellow*) has been awarded the Langley Gold Medal, the first time the Award has been granted since 1953.

SOCIETY OF AUTOMOTIVE ENGINEERS

Sir Harry Ricardo (*Fellow*) was awarded the 1953 Horning Memorial Award by the Society of Automotive Engineers in June 1955 in recognition of distinguished active service during his many years in the field of mutual adaption of fuels and engines.

COLLEGE OF TECHNOLOGY BIRMINGHAM

Sir Frederick Handley Page (*Honorary Fellow*) has been made an Honorary Associate of the College of Technology Birmingham, for his services to the Aircraft Industry and to technical education.

INSTITUTION OF MECHANICAL ENGINEERS

Dr. I. Sikorsky (*Honorary Fellow*) has been awarded the James Watt International Medal.

DANIEL GUGGENHEIM MEDAL BOARD

Dr. Theodore von Kármán (*Honorary Fellow*) has been awarded the Guggenheim Medal for 1955 for his "long continued leadership in the development of aerodynamic theory and in its application to the practical problems of flight; in education in the aeronautical sciences; and in stimulating international co-operation in aeronautical research."

AIR MAIL PIONEERS

Mr. Jerome Lederer (*Associate Fellow*) has been elected a National Vice-President of the Air Mail Pioneers.

LA LEGION D'HONNEUR

Dr. Edward P. Warner (*Honorary Fellow*) has been named a Commander of the Legion of Honour by the French Government for his outstanding work in civil aviation, particularly within the framework of I.C.A.O.

MEDAILLE DE L'AERONAUTIQUE

Monsieur Jean Brocard (*Associate Fellow*) has been awarded the Medaille de l'Aéronautique.

Medals and Awards of the Society

The following Medals and Prizes of the Society were awarded for 1955:—

The Society's Gold Medal, the highest honour which the Society can confer for work of an outstanding nature in Aeronautics, to:

LORD HIVES (*Honorary Fellow*), for his outstanding work in the field of Propulsion of Aircraft.

The Society's Silver Medal, for work of an outstanding nature in Aeronautics, to:

DR. R. A. FRAZER (*Fellow*), for his outstanding work in Aerodynamics over a period of many years; and

DR. A. A. GRIFFITH, for his outstanding research contributions on Aircraft Engine Design.

The Society's Bronze Medal, for work leading to an advance in Aeronautics, to:

PROFESSOR M. J. LIGHTHILL, for his contributions to Aeronautical Knowledge.

The British Gold Medal, for outstanding practical achievement leading to advancement in Aeronautics, to:

MR. G. H. DOWTY (*Fellow*), for his outstanding practical achievement in the design and development of Aircraft Accessory Systems.

The British Silver Medal, for practical achievement leading to advancement in Aeronautics, to:

DR. S. G. HOOKER (*Fellow*), for his practical achievement in the Design and Development of Aero Engines.

The Wakefield Gold Medal, awarded to the Designer or Inventor of any apparatus tending towards safety in Flying, to:

MR. J. TAYLOR (*Associate Fellow*), for the design and development of the Counting Acce'erometer.

The George Taylor (of Australia) Gold Medal, awarded for the most valuable contribution read before or published by the Society on Aircraft Design, Manufacture or Operation, to:

MR. R. C. MORGAN (*Fellow*), for his paper on "Practical Experience of Airline Engineering" (September 1954 Journal).

The Simms Gold Medal, awarded for the most valuable contribution read before, or published by, the Society on any subject allied to Aeronautics, to:

DR. D. WILLIAMS (*Fellow*), for his paper on "Recent Developments in the Structural Approach to Aeroelastic Problems" (June 1954 Journal).

R. P. Alston Memorial Prize, awarded for practical achievement associated with the Flight Testing of Aircraft, to:

MR. G. A. V. TYSON (*Associate Fellow*), for his contributions to the Flight Testing of Marine Aircraft.

The Edward Busk Memorial Prize, awarded for the most valuable contribution read before, or published by, the Society on Applied Aerodynamics, to:

MR. J. C. WIMPENNY (*Associate Fellow*), for his paper on "Stability and Control in Aircraft Design" (May 1954 Journal).

The Herbert Akroyd Stuart Memorial Prize, awarded for the most valuable contribution read before, or published by, the Society on Applied Thermodynamics, to:

MR. E. E. CHATTERTON (*Fellow*), for his paper on "Compound Diesel Engines for Aircraft" (September 1954 Journal).

The Usborne Memorial Prize, awarded for the best contribution to the Society's Publications written by a Graduate or Student on some subject of a Technical Nature in connection with Aeronautics, to:

MR. L. F. CRABTREE (*Graduate*), for his paper on "The Compressible Laminar Boundary Layer on a Yawed Infinite Wing" (Volume V, Part 2, *The Aeronautical Quarterly*, July 1954).

The Orville Wright Prize, awarded for the best contribution received for publication in *The Aeronautical Quarterly* of the Society on some subject of a Technical Nature, in connection with Aeronautics, to:

MESSRS. D. B. SPALDING and B. S. TALL, for their paper on "Flame Stabilisation in High Velocity Gas Streams and the Effect of Heat Losses at Low Pressures" (Volume V, Part 3, *The Aeronautical Quarterly*, September 1954).

The J. E. Hodgson Prize, awarded for the best paper of a general nature with emphasis on Historical Work, published by the Society, jointly to:

MAJOR G. P. BULMAN (*Fellow*), for the First Barnwell Memorial Lecture (June 1954 Journal); and
MR. J. SMITH (*Fellow*), for the First Mitchell Memorial Lecture (May 1954 Journal).

The Branch Prize, awarded for the best paper on an Aeronautical subject read before the Branches and published by the Society, to:

MR. E. CHAMBERS for his paper on "Meteorological Services for the Comet" (March 1954 Journal).

The Royal Aeronautical Society Navigation Prize, awarded for the best paper on Navigation, including Meteorological Instruments and Test Equipment, published by the Society, to:

MR. J. F. W. MERCER, for his paper on "A Quantitative Study of Instrument Approach" (February 1954 Journal).

The R.38 Memorial Fund: Two awards from the Fund were made to:

LORD VENTRY (*Companion*), to assist him in the carrying out of experiments and to help in the development of the Airship *Bournemouth*; and
MR. W. N. ALCOCK (*Companion*), to assist him in his further investigations in connection with Airships.

Elliot Memorial Prize

The Elliott Memorial Prize has been awarded to the following who obtained the highest marks in the General Studies Examination at Halton:

Sergeant Aircraft Apprentice P. J. Arthur (September 1952 Entry)

Corporal Aircraft Apprentice D. J. Morgan (January 1953 Entry).

Baden-Powell Prize

The Baden-Powell Prize has been awarded to H. F. C. Newby, who was considered to be the best student in the June 1955 Associate Fellowship Examination and to Mr. J. Pickard, who was considered to be the best student in the December 1955 entry.

E. J. N. Archbold Memorial Prize

The following have been awarded:—

W. J. D. Brooks and E. J. John	1954
T. T. Greenslade	1955

JOURNAL PREMIUM AWARDS

A list of Premium Awards made in 1954 was published in the May 1955 issue of the JOURNAL of the Society.

BUSK STUDENTSHIP IN AERONAUTICS

The Edward Busk Studentship in Aeronautics was awarded to Mr. James Ian Dodds.

ROYAL AERONAUTICAL SOCIETY CHARTER SCHOLARSHIP

The Charter Scholarship for 1955/56 was awarded to Mr. T. J. Black.

GEOFFREY DE HAVILLAND MEMORIAL SCHOLARSHIP

The Geoffrey de Havilland Memorial Scholarship for 1955/56 was awarded to Mr. E. A. Boyd.

GRANTS FROM THE EDUCATION FUND

Grants in aid of further study and research in aeronautics have been awarded to the following:

Michael Geoffrey Bader
Edgar Allinson Bunt
Edward Michael Cowburn
Michael A. P. Wilmer
A. L. Knight.

ROYAL AERONAUTICAL SOCIETY PRIZES IN AERONAUTICS

The following awards have been made for 1954:

Imperial College of Science and Technology: R. W. Penny and A. J. Taylor-Russell.

Queen Mary College: E. B. Davies.

University of Bristol: R. L. Dommett.
University of Southampton: M. A. Hollingsworth.
University of Glasgow: Ian A. M. Hall.

The following awards have been made for 1955:

University of Southampton: P. A. Knowles and P. Talbot.
Queen Mary College: C. W. Skingle.
University of Bristol: O. P. Nicholas and R. R. Philpot.
University of Glasgow: Thomas Adam.
Cambridge University: A. J. Sarnecki.

Finance

The Income and Expenditure Accounts and Balance Sheets of the Royal Aeronautical Society, and the Aeronautical Trust Limited for 1955 are published with this Report (pp. 262-273).

The Fifth Anglo-American Aeronautical Conference

A Report on the Anglo-American Aeronautical Conference was published in the October issue of the Journal.

On 3rd March 1956 an "At Home" for delegates to the Conference was held in the offices of the Society and after tea and talk a show of coloured transparencies and films was given in the Council Room, supplementing the display of photographs which had been shown in the Library. This gathering was much enjoyed by everyone, especially the wives of the delegates who were meeting once again those whom they had possibly not seen since the Conference in Los Angeles.

Officers and Committees

The Council has been very well served over the year by the hard working members of the Committees of the Society. The work of some of the Committees is arduous and entails the members giving up much of their own time. The Council are grateful to them.

Technical

At the end of October, D. C. Smith resigned from his position as Head of the Technical Department to take up an appointment with A.G.A.R.D. As a consequence of this, the responsibilities for the technical work have been shared jointly between Mr. A. J. Barrett and Mr. J. A. Dunsby, the former becoming Head of the Structures Group with responsibility for the Structural and Fatigue work and the latter Head of the Aerodynamics Group with responsibility for Aerodynamics, Performance and Fuels and Lubricants.

Twenty-one new Structures Data Sheets have been completed and are at present being circulated to all subscribers. In this issue are included a group on generalised data on materials applicable to a wide range of aluminium alloys, titanium alloys and high strength steels, and a group on the buckling of flat plates under biaxial stress systems. Thirty-nine existing data sheets have been reprinted.

The work on fatigue, initially under the guidance of the Structures Committee, has now passed to the new Fatigue Committee, although close liaison is being maintained between the two. Programmes of investigation initiated by the Society, or in which the Society is co-operating, include a photoelastic/fatigue investigation on the strength of bolted joints, the effect of speed on testing and the comparison of scatter in fatigue results for two materials. Results of these are becoming available and some have already been reported in the Society's Journal and Quarterly. Considerable interest in this work is being shown by a number of organisations.

The work of extension and revision of the Aerodynamics Data Sheets has continued and in the past year twenty-one new or revised sheets were completed and issued to subscribers. These sheets covered a wide range of subjects, but particularly noteworthy are the revision of the sheets dealing with the rolling moment derivatives and a new group of sheets giving data on aerodynamic heating. Reprinting of existing sheets has continued where necessary.

During the year work has been started on the printing of a series of new Fuels and Lubricants Data Sheets. These deal with the properties of engine lubricating oils. Revisions of some of the existing fuels sheets are also being made. It is anticipated that a new issue of Fuels and Lubricants sheets will be made in the next few months.

TECHNICAL COMMITTEES

Aerodynamics Committee

Professor A. D. Young (*Chairman*)	Mr. R. Melling
Mr. P. J. Duncton	Mr. R. A. Shaw
Mr. J. W. Fozard	Mr. J. C. Stevenson
Dr. D. W. Holder	Mr. H. H. B. M. Thomas
	Mr. A. K. Weaver

Fatigue Committee

Mr. H. L. Cox (*Chairman*)	Mr. H. B. Howard
Mr. R. J. Atkinson	Mr. N. H. Mason
Mr. G. Forrest	Mr. R. H. Sandifer
Mr. H. Giddings	Mr. W. Tye

Fuels and Lubricants Committee

Mr. E. L. Bass (*Chairman*)	Mr. F. L. Garton
Mr. A. E. Bingham	Mr. C. D. Holland
Professor F. H. Garner	Mr. G. Morris

Performance Committee

Mr. A. H. Yates (*Chairman*)	Mr. T. V. Somerville
Mr. W. J. D. Annand	Mr. C. F. Toms
Mr. H. Davies	Mr. R. H. Whitby
Mr. S. R. Hughes	

Structures Committee

Mr. H. B. Howard (*Chairman*)	Mr. E. D. Keen
Mr. H. L. Cox	Mr. K. L. C. Legg
Professor W. S. Hemp	Mr. F. Tyson
Mr. D. James	Dr. P. B. Walker

The detailed report on the Technical Work of the Society will be published in the Society's JOURNAL later in 1956.

Staff

The major change in the Staff of the Society came through the resignation of Mr. D. C. Smith who, in October 1955, joined A.G.A.R.D. in Paris.

In February 1956, Mr. A. S. C. Lumsden joined the Staff, and he is looking after the Membership of the Society.

The Council are pleased to welcome Mr. Nigel B. Joyce who has been seconded from the Aeronautical Research Laboratories at Fishermen's Bend, Melbourne, to the Technical Staff of the Society.

The Council congratulate Miss Barwood on receiving the M.B.E. in the New Year's Honours List 1956.

Donations

Donations have been received during 1955 from the following:

Blackburn and General Aircraft Limited
Bristol Aeroplane Company Limited
de Havilland Aircraft Company Limited
Dowty Equipment Limited
English Electric Group
Folland Aircraft Limited
Hawker Siddeley Group
Hunting Percival Aircraft Limited
Rolls-Royce Limited
Vickers-Armstrongs Limited
Westland Aircraft Limited
Society of British Aircraft Constructors
Ministry of Supply.

The Society has also received grants from:

Society of British Aircraft Constructors, and
Ministry of Supply

for technical work.

These the Council wish to acknowledge with gratitude and thanks.

Library

The acquisition of a further 290 items still further strained the Library accommodation but this was partially offset by discarding redundant material during the work of recataloguing—a work which is now complete as far as the books in the main library are concerned. There was a further drop in the number of loans made (917) but there was a considerable increase in the telephone enquiries.

Several new periodicals have been taken and the renaissance of aeronautics in Germany has meant the addition of a number of new or re-born reports. The periodical coverage is now systematically indexed.

The Library room is increasingly in demand for both Society and "outside" meetings and while this involves the removal of the displayed periodicals and the tables on which they rest, it is done with the minimum of inconvenience to users.

There were a few gifts of old aeronautical material—photographs, papers, letters, reports—but the Library's appetite is insatiable. That the acquisition of such material is justified was made evident by the help which was given to various bodies in providing background displays for exhibitions and to authors in providing illustrations for books, papers, etc.

During the year Miss Marshall left, after some ten years' service, to take an appointment in America and her place as cataloguer has been taken by Miss A. Blanshard.

Publications

THE JOURNAL has continued to make progress and once more on account of the increase in membership of the Society and additional subscriptions, the number of copies printed in 1955 was greater than ever. More Section Lectures are now being published and the number of papers submitted for publication continues to increase. The Technical Note section is proving a useful forum and more contributions to this are being received from abroad.

Experiments have been continued with envelopes and wrappers and during the latter half of 1955 all Journals, both home and abroad, were sent out in wrappers. Many members have expressed their preference for envelopes but because of greater production and postage costs in 1956, the use of wrappers is being continued; the cost of envelopes is almost double that of wrappers. The situation is being kept under review.

On account of the increased costs of production and distribution in 1956, the annual subscription to the Journal has been increased, as from January 1956, to £7 10s. 0d., plus 9s. postage and packing; the cost of single copies has now become 12s. 6d. each, plus 9d. postage and packing.

Publication of the YEAR BOOK was later than had been hoped but it was sent to all members in December 1955, the List of Members being correct as at the 1st September. Unfortunately a number of members omitted to return the cards which had been sent to them earlier in the year so the Classified Section was far from complete but, in spite of some errors and omissions, the Year Book and List of Members is obviously filling a long-felt want.

THE AERONAUTICAL QUARTERLY continued to consolidate its position during the year and sales of the four issues published in 1955 were greater than those for the previous volume. The number of papers submitted for publication has increased considerably; this may be due partly to the reduction of the delay in publication since the Quarterly reverted to four issues a year. Inevitably this increase in the supply of material and demand for publication, although it helps to maintain the high standard of the Quarterly, tends itself to lengthen the publication delay, when the space available is limited. At the beginning of 1956 Miss E. C. Pike, Technical Editor, was appointed Editor of the Quarterly.

No new MONOGRAPHS were published during the year but sales of the four already sponsored by the Society, three on materials and one on massbalancing of controls, continued. A fifth monograph, on instrumentation, and two text-books, one on hydraulics and the other on landing gear design, are in the press and should be published in 1956.

The steady sales of DATA SHEETS have necessitated a considerable amount of reprinting and altogether about 150 data sheets, including new sheets, were printed during the year.

Associate Fellowship Examination

The Associate Fellowship Examinations have been held in June and December 1955, under both the old and the new Syllabus. The number of candidates at home and abroad in June was 106 and in December the number was 117. The Examination was held in the following countries at the various Universities and Institutions whose help is greatly appreciated by the Council.

Australia, Canada, Egypt, Holland, Iraq, Israel, India, Germany, Norway, Pakistan, Switzerland, New Zealand and in B.A.O.R.

A list of those candidates who were successful in the June examinations was published in the September 1955 Journal and the successful candidates in the December examinations are published in this Journal.

Royal Aeronautical Society Education Fund

A Royal Aeronautical Society Education Fund has been established, and from it have been given grants to students to enable them to overcome financial stress, and the recipients have expressed their appreciation of the benevolent thought of the Society in founding such a Fund.

The purpose of the Fund is to assist Education in its many forms by making grants for such things as tuition, books, or apparatus, or even to make smoother the financial path of the needy student. Full particulars may be obtained from the Secretary.

THE ROYAL

(INCORPORATED

BALANCE SHEET

1954 Figures £		£ s. d.	£ s. d.	£ s. d.
	CURRENT LIABILITIES			
5542	Sundry Creditors		9931 9 6	
4572	Subscriptions and other amounts received in advance		4987 17 6	
				14969 7 0
	SURPLUS (subject to depreciation of Investments)			
	Reserve for Anglo-American Conferences			
	Balance at 31st December 1954		3500 0 0	
	Add transfer from Income and Expenditure Account		1500 0 0	
			5000 0 0	
	Deduct Expenditure less receipts during year		3065 2 10	
3500			1934 17 2	
	Income and Expenditure Account			
	Balance at 31st December 1954	14503 7 9		
	Add Surplus of Income over Expenditure for year to date	629 14 2		
			15133 1 11	
14503				17067 19 1
£28117				£32037 6 1

N. E. ROWE,
President.

G. P. BULMAN,
Honorary Treasurer.

REPORT OF THE AUDITORS TO THE MEMBERS

In our opinion and to the best of our information and according to the expenditure account of the Society together with the accounts of the Royal Aeronautical Limited give a true and fair view of the state of the Society's affairs as at 31st December

We have obtained all the information and explanations which to the best of kept proper books of account and the above mentioned accounts are in agreement

3 Frederick's Place, Old Jewry, London, E.C.2.
23rd March 1956.

AERONAUTICAL SOCIETY

BY ROYAL CHARTER 1949)

31st DECEMBER 1955

1954 Figures £		£ s. d.	£ s. d.
	CURRENT ASSETS		
1	Stock of Journals and other publications	1 0 0	
11098	Sundry Debtors	13170 8 11	
739	Payments in advance	700 7 4	
5230	Balances at Bank and Cash in Hand	7107 4 11	
			20979 1 2
5600	INVESTMENTS AT COST Market Value 31st December 1955 £4,543 (1954 £5,355)		5600 0 0
	AERONAUTICAL TRUSTS LIMITED		
1	21 shares of 1/- each fully paid at cost	1 1 0	
54	Amount due on current account	63 8 11	
			64 9 11
	PRINTED BOOKS, BINDINGS, OLD PRINTS, ETC.		
50	At nominal amount		50 0 0
	NASH COLLECTION OF HISTORICAL AIRCRAFT		
5344	At cost		5343 15 0
£28117			£32037 6 1

OF THE ROYAL AERONAUTICAL SOCIETY

explanations given to us, the above balance sheet and the annexed income and Society Endowment Fund included in the annexed accounts of Aeronautical Trusts 1955 and of its surplus for the year ended on that date.

our knowledge and belief were necessary for our audit. In our opinion the Society has therewith.

(*Signed*) PRICE WATERHOUSE & CO.

THE ROYAL

INCOME AND EXPENDITURE ACCOUNT

1954 Figures £		£ s. d.	£ s. d.
	To ESTABLISHMENT EXPENSES		
2730	Ground Rent, Heating, Lighting, Insurance and Repairs ..		3436 13 1
	„ ADMINISTRATIVE AND OFFICE EXPENSES		
10506	Salaries and National Insurance	10699 5 9	
1564	Pension and Pension Premiums	1538 9 6	
1754	Printing and Stationery	2082 15 10	
1508	Postages and Telephones	1689 2 6	
366	Office Furniture and Equipment	329 4 10	
343	Travelling Expenses	469 2 2	
871	Other Charges	1173 14 5	
16912			17981 15 0
	„ JOURNAL AND PUBLICATIONS		
3267	Salaries and Pension Premiums	3956 9 9	
19559	Printing	19082 15 10	
—	Printing Year Book	3185 11 5	
2463	Postages and Envelopes	2611 4 4	
1536	Other expenses	1610 17 6	
26825			30446 18 10
	„ TECHNICAL COMMITTEES		
6951	Salaries and Pension Premiums	6904 17 4	
3338	Printing and other charges	4320 16 0	
—	Travelling Expenses	80 16 7	
10289			11306 9 11
	„ *GARDEN PARTY*		
2071	*Expenses*		—
683	„ EXAMINATIONS EXPENSES		606 1 4
945	„ MEETINGS		566 14 5
1500	„ ANGLO-AMERICAN AERONAUTICAL CONFERENCES RESERVE ..		1500 0 0
359	„ DINNERS AND RECEPTIONS		562 18 8
	„ LIBRARY		
1766	Salaries and Pension Premiums	1602 13 4	
379	Expenses	346 12 1	
2145			1949 5 5
540	„ GRANTS TO BRANCHES AND SECTIONS		560 0 0
170	„ PRIZES AND DONATIONS		265 19 5
400	„ CHARTER SCHOLARSHIPS		300 0 0
410	„ LEGAL AND PROFESSIONAL CHARGES		305 11 0
365	„ PAYMENT TO CANADIAN AERONAUTICAL INSTITUTE		364 9 8
—	„ CONTRIBUTION TOWARDS COST OF CAPTAIN PRITCHARD'S LECTURE TOUR IN THE U.S.A.		500 0 0
1448	„ *SECRETARY'S VISITS TO THE DOMINIONS*		—
1331	„ BALANCE BEING SURPLUS OF INCOME OVER EXPENDITURE FOR YEAR CARRIED TO BALANCE SHEET		629 14 2
£69123			£71282 10 11

AERONAUTICAL SOCIETY

FOR THE YEAR ENDED 31st DECEMBER 1955

1954 Figures £			£ s. d.	£ s. d.
25312		By ANNUAL SUBSCRIPTIONS		25738 7 9
11038		„ DONATIONS AND GRANTS		11213 12 8
226		„ INTEREST ON INVESTMENTS (GROSS)	168 0 0	
52		„ *INCOME TAX RECOVERED*	—	
5090		„ SURPLUS ON ENDOWMENT FUND INCOME AND EXPENDITURE ACCOUNT FOR YEAR	5229 12 11	
	5368			5397 12 11
127		„ *PROFIT ON SALE OF INVESTMENT*		—
		„ JOURNAL AND PUBLICATIONS		
15207		Advertising Revenue	14947 15 8	
—		Advertising Revenue Year Book	1874 10 0	
			16822 5 8	
7654		Sales	8583 8 1	
	22861			25405 13 9
		„ TECHNICAL COMMITTEES		
2290		Sales		2870 9 4
		„ *GARDEN PARTY*		
1247		*Sale of Tickets*		—
251		*Profit on Programme*		—
	1498			
629		„ EXAMINATIONS FEES		656 14 6
£69123				£71282 10 11

BALANCE SHEET

1954 Figures £		£ s. d.	£ s. d.	£ s. d.
	SHARE CAPITAL			
	AUTHORISED: 40 shares of 1s. each		2 0 0	
1	ISSUED: 21 shares of 1s. each fully paid			1 1 0
	ROYAL AERONAUTICAL SOCIETY ENDOWMENT FUND			
	CAPITAL ACCOUNT (Subject to depreciation of investments)			
133490	Balance at 31st December 1954		134358 19 8	
836	*Add* Entrance Fees received during year		853 14 0	
43	*Profit on Sale of Investments*		—	
			135222 13 8	
	INCOME ACCOUNT			
9104	Balance as at 31st December 1954		9103 14 6	
143473				144326 8 2
	PILCHER MEMORIAL FUND			
	CAPITAL ACCOUNT			
100	As at 31st December 1954		99 14 0	
	INCOME ACCOUNT			
80	Balance at 31st December 1954	74 18 8		
5	*Add* Income for year to date	5 7 4	80 6 0	
(Excess)				180 0 0
175				
	USBORNE MEMORIAL FUND			
	CAPITAL ACCOUNT			
109	As at 31st December 1954		109 2 5	
	INCOME ACCOUNT			
90	Balance at 31st December 1954	85 4 4		
5	*Less* Excess of Expenditure over Income for year to date	4 10 8	80 13 8	
194				189 16 1
	HERBERT AKROYD STUART FUND			
	CAPITAL ACCOUNT			
691	As at 31st December 1954		691 9 0	
	INCOME ACCOUNT			
633	Balance at 31st December 1954	677 2 11		
44	*Add* Surplus of Income over Expenditure for year to date	25 13 11	702 16 10	
1368				1394 5 10
	R.38 MEMORIAL FUND			
	CAPITAL ACCOUNT			
982	As at 31st December 1954		981 13 10	
	INCOME ACCOUNT			
1107	Balance at 31st December 1954	1175 11 4		
68	*Less* Excess of Expenditure over Income for year to date	28 0 7	1147 10 9	
(Income)				2129 4 7
2157				
147368	*Forward*			148220 15 8

TRUSTS LIMITED

31st DECEMBER 1955

1954 Figures £		£ s. d.	£ s. d.	£ s. d.
1	CASH IN HAND			1 1 0
	ROYAL AERONAUTICAL SOCIETY ENDOWMENT FUND			
	Leasehold Property at cost *less* amounts written off			
	4, 8 and 9 Hamilton Place			
14185	At cost	14185 1 9		
8436	*Less* Amortisation written off to date	9091 1 9		
5749			5094 0 0	
	Furniture at cost *less* depreciation			
6396	At cost	6396 1 11		
3584	*Less* Depreciation written off to date	3904 1 11		
2812			2492 0 0	
131076	Investments at cost		133859 1 11	
	Market value 31st December 1955 £114,381 (1954 £126,544)			
			141445 1 11	
	Current Assets			
375	Sundry Debtors	375 0 0		
3515	Balance at Bank	2569 15 2	2944 15 2	
143527			144389 17 1	
54	*Less* Amount due to the Royal Aeronautical Society		63 8 11	
143473				144326 8 2
	PILCHER MEMORIAL FUND			
156	Investment at cost		156 5 0	
	Market Value 31st December 1955 £118 (1954 £134)			
19	Balance at Bank		23 15 0	
175				180 0 0
	USBORNE MEMORIAL FUND			
175	Investment at cost		174 11 1	
	Market Value 31st December 1955 £131 (1954 £149)			
19	Balance at Bank		15 5 0	
194				189 16 1
	HERBERT AKROYD STUART FUND			
1278	Investments at cost		1278 11 1	
	Market Value 31st December 1955 £987 (1954 £1127)			
90	Balance at Bank		115 14 9	
1368				1394 5 10
	R.38 MEMORIAL FUND			
2005	Investments at cost		2004 18 9	
	Market Value 31st December 1955 £1525 (1954 £1741)			
152	Balance at Bank		124 5 10	
2157				2129 4 7
147368	*Forward*			148220 15 8

BALANCE SHEET—*Continued*

1954 Figures £		£ s. d.	£ s. d.	£ s. d.
147368	*Forward*			148220 15 8
	EDWARD BUSK MEMORIAL FUND			
	CAPITAL ACCOUNT			
449	As at 31st December 1954		449 6 1	
	INCOME ACCOUNT			
243	Balance at 31st December 1954	246 5 11		
	Add Surplus of Income over Expenditure for year			
4	to date	3 10 4	249 16 3	
696				699 2 4
	EDWARD BUSK STUDENTSHIP IN AERONAUTICS			
	CAPITAL ACCOUNT			
5421	As at 31st December 1954		5420 10 4	
	INCOME ACCOUNT			
147	Balance at 31st December 1954	203 17 0		
	Add Surplus of Income over Expenditure for year			
56	to date	89 19 1	293 16 1	
5624				5714 6 5
	WILBUR WRIGHT MEMORIAL FUND			
	CAPITAL ACCOUNT			
2137	Balance at 31st December 1954		2136 17 11	
—	*Add* Donation received during year		75 0 0	
			2211 17 11	
	INCOME ACCOUNT			
202	Balance at 31st December 1954	183 7 10		
	Less Excess of Expenditure over Income for year			
19	to date	9 5 4	174 2 6	
2320				2386 0 5
	SIMMS GOLD MEDAL FUND			
	CAPITAL ACCOUNT			
528	As at 31st December 1954		527 15 9	
	INCOME ACCOUNT			
93	Balance at 31st December 1954	106 10 0		
	Add Surplus of Income over Expenditure for year			
14	to date	14 17 1	121 7 1	
635				649 2 10
	ALSTON MEMORIAL FUND			
	CAPITAL ACCOUNT			
250	As at 31st December 1954		250 8 10	
	INCOME ACCOUNT			
80	Balance at 31st December 1954	84 1 7		
	Add Surplus of Income over Expenditure for year			
4	to date	1 3 0	85 4 7	
334				335 13 5
	GEOFFREY DE HAVILLAND MEMORIAL FUND			
	CAPITAL ACCOUNT			
4176	As at 31st December 1954		4175 17 5	
	INCOME ACCOUNT			
330	Balance at 31st December 1954	340 16 8		
	Add Surplus of Income over Expenditure for year			
11	to date	20 19 9	361 16 5	
4517				4537 13 10
£161494				£162542 14 11

REPORT OF THE AUDITORS TO THE

In our opinion and to the best of our information and according to the explanations true and fair view of the state of the Company's affairs and of the Funds administered by it

We have obtained all the information and explanations which to the best of our proper books of account and the above mentioned accounts, which are in agreement therewith.

3 Frederick's Place, Old Jewry, London, E.C.2.
23rd March 1956.

TRUSTS LIMITED

31st DECEMBER 1955

1954 Figures £		£ s. d.	£ s. d.
147368	*Forward*		148220 15 8
	EDWARD BUSK MEMORIAL FUND		
658	Investments at cost	658 8 8	
	Market Value 31st December 1955 £559 (1954 £648)		
38	Balance at Bank	40 13 8	
696			699 2 4
	EDWARD BUSK STUDENTSHIP IN AERONAUTICS		
	Investments at valuation 31st December 1951	4806 10 0	
	Investments at cost	601 6 6	
	Market Value 31st December 1955 £5209 (1954 £5759)		
5408		5407 16 6	
216	Balance at Bank	306 9 11	
5624			5714 6 5
	WILBUR WRIGHT MEMORIAL FUND		
2251	Investments at cost	2250 14 9	
	Market Value 31st December 1955 £2091 (1954 £2272)		
69	Balance at Bank	135 5 8	
2320			2386 0 5
	SIMMS GOLD MEDAL FUND		
585	Investments at cost	585 0 0	
	Market Value 31st December 1955 £466 (1954 £537)		
50	Balance at Bank	64 2 10	
635			649 2 10
	ALSTON MEMORIAL FUND		
295	Investment at cost	295 2 10	
	Market Value 31st December 1955 £244 (1954 £278)		
39	Balance at Bank	40 10 7	
334			335 13 5
	GEOFFREY DE HAVILLAND MEMORIAL FUND		
4427	Investments at cost	4426 10 0	
	Market Value 31st December 1955 £3451 (1954 £4072)		
90	Balance at Bank	111 3 10	
4517			4537 13 10
£161494			£162542 14 11

MEMBERS OF AERONAUTICAL TRUSTS LIMITED

given to us the above balance sheet and the annexed income and expenditure account give a as at 31st December 1955 and of the surplus of the Funds for the year ended on that date.

knowledge and belief were necessary for our audit. In our opinion the company has kept give in the prescribed manner the information required by the Companies Act, 1948.

(*Signed*) PRICE WATERHOUSE & CO.

AERONAUTICAL

INCOME AND EXPENDITURE ACCOUNTS

ROYAL AERONAUTICAL SOCIETY

1954 Figures		£ s. d.
£		
655	To Amortisation of Leasehold Property	655 0 0
320	„ Depreciation of Furniture	320 0 0
8	„ Legal Expenses	8 8 0
5090	„ Surplus of Income over Expenditure for year transferred to the Royal Aeronautical Society	5229 12 11
£6073		£6213 0 11

PILCHER

		£ s. d.
£		
—	To Income for year carried to Balance Sheet	5 7 4
10 (*Award*)		
£10		£5 7 4

USBORNE

		£ s. d.
£		
10	To 1955 Award	10 10 0
£10		£10 10 0

HERBERT AKROYD

		£ s. d.
£		
—	To 1955 Award	21 0 0
—	„ Surplus of Income over Expenditure for year carried to Balance Sheet	25 13 11
44 (*Award*)		
£44		£46 13 11

R.38

		£ s. d.
£		
—	To 1955 Awards	100 0 0
69 (*Income*)		
£69		£100 0 0

EDWARD BUSK

		£ s. d.
£		
21	To 1955 Award	21 0 0
3	„ Surplus of Income over Expenditure for year carried to Balance Sheet	3 10 4
£24		£24 10 4

TRUSTS LIMITED

FOR THE YEAR ENDED 31st DECEMBER 1955

ENDOWMENT FUND

1954 Figures £		£ s. d.
2642	By Interest on Investments (Gross)	2617 1 4
1096	„ Interest on Investments (*less* tax)	1240 1 7
835	„ Refund of Income Tax	855 18 0
1500	„ Rents Receivable	1500 0 0
£6073		£6213 0 11

MEMORIAL FUND

£		£ s. d.
5	By Interest on Investments (Gross)	5 7 4
5 (*Excess*)		
£10		£5 7 4

MEMORIAL FUND

£		£ s. d.
6	By Interest on Investments (Gross)	5 19 4
4	„ Excess of Expenditure over Income for year carried to Balance Sheet	4 10 8
£10		£10 10 0

STUART FUND

£		£ s. d.
37	By Interest on Investments (Gross)	45 0 6
4	„ *Interest on Investments* (*less tax*)	—
3	„ Refund of Income Tax	1 13 5
£44		£46 13 11

MEMORIAL FUND

£		£ s. d.
60	By Interest on Investments (Gross)	69 11 8
6	„ *Interest on Investments* (*less tax*)	—
3	„ Refund of Income Tax	2 7 9
—	„ Excess of Expenditure over Income for year carried to Balance Sheet	28 0 7
£69		£100 0 0

MEMORIAL FUND

£		£ s. d.
24	By Interest on Investments (Gross)	24 10 4
£24		£24 10 4

AERONAUTICAL

INCOME AND EXPENDITURE ACCOUNTS

1954 Figures

EDWARD BUSK STUDENTSHIP

1954 Figures £		£ s. d.
165	To 1955 Awards	135 0 0
56	„ Surplus of Income over Expenditure for year carried to Balance Sheet	89 19 1
£221		£224 19 1

WILBUR WRIGHT

1954 Figures £		£ s. d.
100	To 1955 Award	100 0 0
£100		£100 0 0

SIMMS GOLD

1954 Figures £		£ s. d.
6	To 1955 Award	5 13 6
13	„ Surplus of Income over Expenditure for year carried to Balance Sheet	14 17 1
£19		£20 10 7

ALSTON

1954 Figures £		£ s. d.
10	To 1955 Award	10 0 0
3	„ Surplus of Income over Expenditure for year carried to Balance Sheet	1 3 0
£13		£11 3 0

GEOFFREY DE HAVILLAND

1954 Figures £		£ s. d.
120	To 1955 Award	113 6 8
11	„ Surplus of Income over Expenditure for year carried to Balance Sheet	20 19 9
£131		£134 6 5

TRUSTS LIMITED

FOR THE YEAR ENDED 31st DECEMBER 1955—*Continued*

1954 Figures

IN AERONAUTICS

1954 Figures £		£ s. d.
135	By Interest on Investments (Gross)	135 17 8
48	„ Interest on Investments (*less* tax)	49 9 9
38	„ Refund of Income Tax	39 11 8
£221		£224 19 1

MEMORIAL FUND

1954 Figures £		£ s. d.
37	By Interest on Investments (Gross)	80 18 4
24	„ *Interest on Investments (less tax)*	
20	„ Refund of Income Tax	9 16 4
19	„ Excess of Expenditure over Income for year carried to Balance Sheet	9 5 4
£100		£100 0 0

MEDAL FUND

1954 Figures £		£ s. d.
16	By Interest on Investments (Gross)	19 15 4
2	„ *Interest on Investments (less tax)*	
1	„ Refund of Income Tax	15 3
£19		£20 10 7

MEMORIAL FUND

1954 Figures £		£ s. d.
13	By Interest on Investments (Gross)	11 3 0
£13		£11 3 0

MEMORIAL FUND

1954 Figures £		£ s. d.
121	By Interest on Investments (Gross)	131 18 8
6	„ *Interest on Investments (less tax)*	
4	„ Refund of Income Tax	2 7 9
£131		£134 6 5

Named Lectures

The Eighth Louis Bleriot Lecture was held in London on 17th March 1955 and the subject was "Making Aeroplanes Independent of Runways" by Monsieur Georges Hereil. (The full report was published in the June 1955 Journal.)

The Eleventh British Commonwealth and Empire Lecture was held in London on 6th October 1955 and the subject was "The Growth of Aeronautical Research in Canada during the Post-War Decade" by Dr. J. J. Green, M.B.E., B.Sc., A.R.C.S., D.I.C., F.I.A.S., F.A.C.I., F.R.Ae.S. (The full report was published in the December 1955 Journal.)

The 43rd Wilbur Wright Memorial Lecture was held in London on 19th May 1955, and the subject was "Flight Control" by Dr. C. S. Draper, F.I.A.S. (The full report was published in the July 1955 Journal.)

Obituaries

The Council regret to record the death of the following Members of the Society:

Major C. F. Abell (*Fellow*)
Robert Blackburn (*Honorary Fellow*)
Louis Breguet (*Honorary Fellow*)
M. F. Burle (*Graduate*)
Dr. W. J. R. Calvert (*Associate*)
A. N. Cooper (*Associate*)
Group Captain W. N. Cumming (*Associate Fellow*)
Flight Lieutenant W. R. B. Currie (*Associate*)
Air Vice-Marshal E. D. Davis (*Associate Fellow*)
I. H. Driggs (*Fellow*)
E. J. Earle (*Associate Fellow*)
C. Fox (*Associate*)
A. C. Freeth (*Associate Fellow*)
J. W. H. Grant (*Student*)
J. D. M. Gray (*Associate*)
W. Greenhalgh (*Associate*)
H. Grinsted (*Honorary Fellow*)
Major F. B. Halford (*Fellow*)
A. J. Henington (*Associate Fellow*)
G. T. R. Hill (*Fellow*)
F. J. Howard (*Associate Fellow*) (Australian Division)
T. Hunt (*Associate*)
H. Hurlin (*Associate*)
J. H. Jagger (*Associate*)
Captain A. G. Lamplugh (*Fellow*)
P. H. Lawrence (*Associate Fellow*)
Lieutenant Colonel F. E. Loudy (*Associate Fellow*)
Sir Francis K. McClean (*Honorary Fellow*)
Glenn L. Martin (*Fellow*)
H. S. Martin (*Associate*)
P. Mitchell (*Associate Fellow*)
N. F. Newbery (*Associate Fellow*)
Flying Officer J. C. Rice (*Associate*)
A. D. Robinson (*Graduate*)
Wing Commander K. J. Sewell (*Associate Fellow*)
Major B. W. Shilson (*Fellow*)
Joseph Smith (*Fellow*)
Marshal of the Royal Air Force Viscount Trenchard of Wolfeton (*Honorary Fellow*)
J. Tustanowski (*Associate Fellow*)

TECHNICAL NOTES

Contributions to this Section of the JOURNAL *will be eligible for Journal Premium Awards and will normally be published within two months of being received.*

End-Fitting Effects in Strut Tests

By

A. H. CHILVER

(Department of Engineering, Cambridge University)

IN A RECENT STUDY of the buckling of pin-ended struts of a certain light-alloy material the author found it necessary to use ball-end fittings which supported rigidly an appreciable length of the strut. For some of the struts —having slenderness ratios of the order of 20—the unsupported length was only about a quarter of the overall length between pinned-ends, (Fig. 1). The effect of rigid end-fittings can easily be taken into account in calculating the elastic buckling load of this system. The author expected to find this end effect important for shorter struts; however, this is not the case. In fact, buckling of the strut is governed largely by the flexibility of the unsupported length, and even large end fittings may not affect appreciably the buckling load.

Knife-edge or ball-end fittings are widely used in strut testing, and it is perhaps relevant to indicate the effects these fittings are likely to produce. The elastic buckling load of a pin-ended strut with rigid end-connections was studied by von Kármán and Biot[1]; it is shown that their approximate solution is very accurate for most practical strut tests. A problem of a similar type was discussed by Baker and Roderick[2], who studied the buckling of light-alloy struts with initial imperfections. In the present note the " tangent-modulus " approach is used in applying the Kármán-Biot solution to buckling beyond the elastic range of the material.

BUCKLING LOAD OF THE STRUT

A straight uniform strut of flexural stiffness EI is attached to end fittings each of " effective " length a; the total length between knife-edge supports is L, (Fig. 2). The " effective " length of the end-fittings is the length which may be regarded as completely rigid from the bending point of view. The end-fittings are arranged so that the compression load P is applied axially. It is easily shown that the elastic buckling load of this system is the root of the equation

$$1-\left[\left(\frac{2a}{L}\right)\theta\right]\tan\left[\left(1-\frac{2a}{L}\right)\theta\right]=0, \quad . \quad (1)$$

in which

$$\theta^2=PL^2/(4EI). \quad . \quad . \quad . \quad (2)$$

The fraction $(2a/L)$ is the proportion of the total length of strut which is rigidly supported. Kármán and Biot[1] note that θ is always greater than $\pi/2$, and put

$$\theta=\frac{\pi}{2}+\varepsilon. \quad . \quad . \quad . \quad (3)$$

Equation (1) is then written in the form

$$\tan\left[\left(\frac{2a}{L}\right)\left(\frac{\pi}{2}\right)-\left(1-\frac{2a}{L}\right)\varepsilon\right]=\left(\frac{2a}{L}\right)\left(\frac{\pi}{2}+\varepsilon\right). \quad (4)$$

Received 14th February 1956

If a and ε are small, an approximate solution of equation (4) is

$$\varepsilon=\frac{1}{3}\left[\left(\frac{2a}{L}\right)\left(\frac{\pi}{2}\right)\right]^3, \quad . \quad . \quad (5)$$

a result given by Kármán and Biot[1]. Equation (4) may also be written in the form

$$\varepsilon=\left[\frac{2a}{L}\left(\frac{\pi}{2}+\varepsilon\right)\right]-\tan^{-1}\left[\frac{2a}{L}\left(\frac{\pi}{2}+\varepsilon\right)\right]. \quad (6)$$

The exact solution of equation (6) is easily found; suppose we give

$$\left[\frac{2a}{L}\left(\frac{\pi}{2}+\varepsilon\right)\right]$$

any value, then ε can be evaluated from equation (6); $(2a/L)$ may then be calculated from the given value of

$$\left[\frac{2a}{L}\left(\frac{\pi}{2}+\varepsilon\right)\right].$$

The relation between $(2\varepsilon/\pi)$ and $(2a/L)$, as defined by

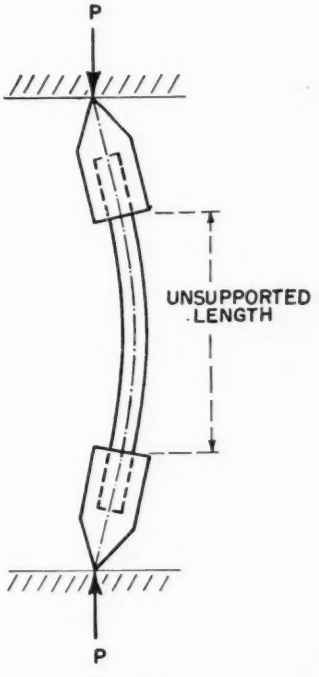

FIGURE 1.

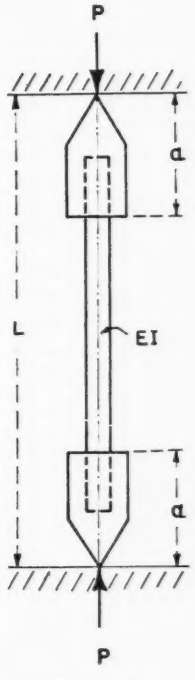

FIGURE 2.

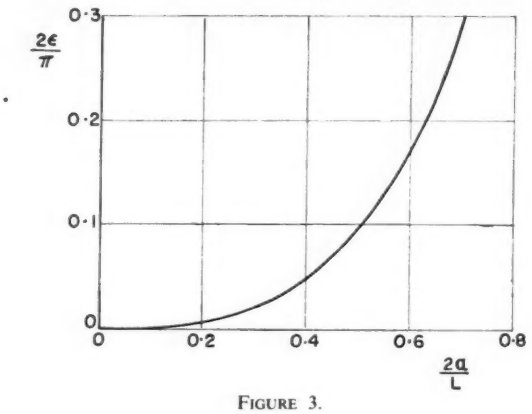

FIGURE 3.

equation (6), is shown in Fig. 3; it is plotted for values of $(2a/L)$ up to 0.7, *i.e.* an unsupported length of $0.3L$. The approximate solution (5) is extremely accurate for $(2a/L) < 0.7$; it is only about 4 per cent. in error at $(2a/L) = 0.7$; this provides a most useful tool for studying the problem more closely.

IMPLICATIONS OF THE APPROXIMATE SOLUTION

On using the approximate value of ε we have

$$\theta = \frac{\pi}{2} + \varepsilon = \frac{\pi}{2}\left[1 + \frac{1}{3}\left(\frac{2a}{L}\right)^3\left(\frac{\pi}{2}\right)^2\right],$$

and the buckling load is

$$P = \frac{\pi^2 EI}{L^2}\left[1 + \frac{1}{3}\left(\frac{2a}{L}\right)^3\left(\frac{\pi}{2}\right)^2\right]^2.$$

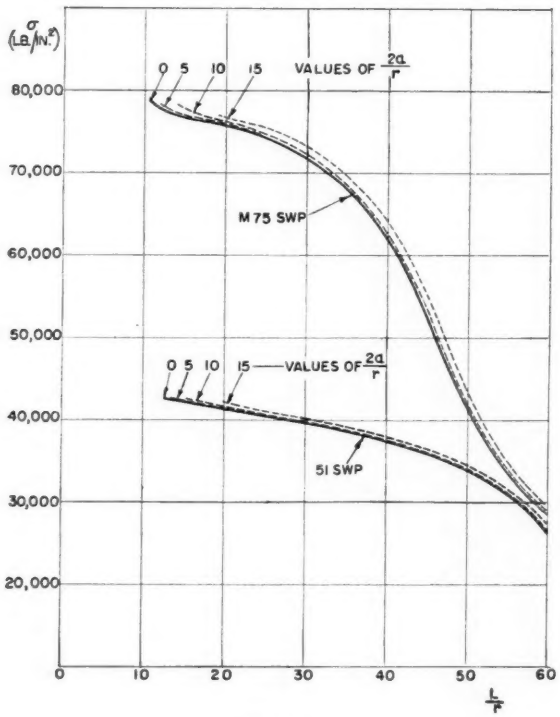

FIGURE 5.

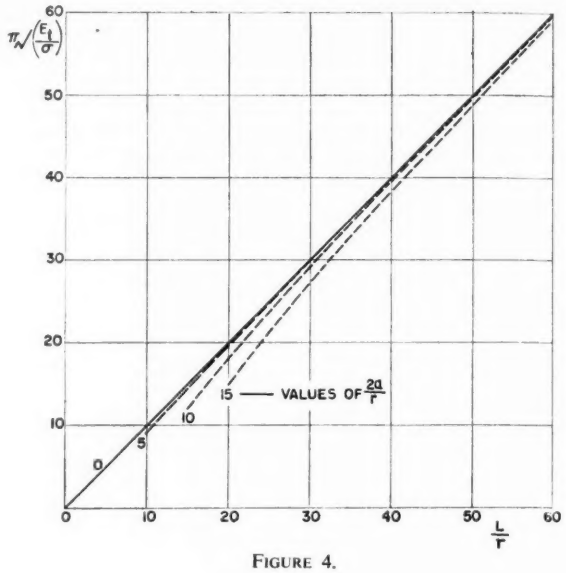

FIGURE 4.

The buckling stress is

$$\sigma = \frac{\pi^2 E}{(L/r)^2}\left[1 + \frac{1}{3}\left(\frac{2a}{L}\right)^3\left(\frac{\pi}{2}\right)^2\right]^2, \quad . \quad (7)$$

where r is the relevant radius of gyration, and (L/r) is the slenderness ratio of the strut. On re-arranging equation (7) we have

$$\pi\sqrt{\frac{E_t}{\sigma}} = \frac{(L/r)}{\left[1 + \frac{1}{3}\left(\frac{\pi}{2}\right)^2\frac{(2a/r)^3}{(L/r)^3}\right]}, \quad . \quad (8)$$

in which the tangent modulus E_t is introduced in place of the elastic modulus E to generalise the solution for both plastic and elastic buckling. For any material the function $\pi\sqrt{(E_t/\sigma)}$ is defined for any value of σ. The function on the right-hand side of equation (8) is defined for any values of (L/r) and $(2a/r)$; it is plotted in Fig. 4 for $(2a/r)$ equal to 5, 10 and 15. The value 15 is perhaps an extreme practical condition; the maximum value of $(2a/r)$ used in the author's tests was about 10. Usually $(2a/r)$ will not exceed 5 or so, and the corresponding curve in Fig. 4 shows the negligible effect of end-fittings of this sort.

The buckling stress for any slenderness ratio (L/r) and any value $(2a/r)$ is easily found from Fig. 4 by noting the value of $\pi\sqrt{(E_t/\sigma)}$; it then remains to find the corresponding value of σ from the stress-strain curve of the material.

MODIFIED STRUT CURVES FOR TWO LIGHT-ALLOY MATERIALS

The effect of end-fittings depends largely on the form of the stress-strain curve of the material under test. Durham[3] has compiled stress-strain curves for a number of "Noral" wrought alloys, and two of these—51 SWP and M 75 SWP, both in extruded form—are used as a basis of study. Average properties of these alloys are:—

	51 SWP	M 75 SWP	
0·1 per cent. Proof stress	41,000	76,000	lb./in.²
Elastic modulus	$9{\cdot}5 \times 10^6$	$10{\cdot}6 \times 10^6$	lb./in.²

The first material is a medium strength alloy; the second has a considerably higher proof stress. Values of the tangent-modulus, E_t, for these materials are given by Durham[3] for all relevant values of the compression stress, σ. In this way the function $\pi\sqrt{(E_t/\sigma)}$ is easily calculated for any value of σ. The effect of rigid end-fittings is to increase the buckling load of a simple pin-ended strut: buckling stresses derived from equation (8) are shown for the two materials in Fig. 5. For the medium strength alloy, 51 SWP, the increase in buckling stress when $(2a/r)$ is equal to 15 is never greater than 3 per cent.—4 per cent. in the important range of slenderness ratios. In the case of the higher strength alloy, M75 SWP, the effect of $\frac{2a}{r}=15$ is the order of 5 per cent.

CONCLUSIONS

The value $\frac{2a}{r}=15$ is perhaps an extreme practical condition. Even in this case the effect of the end-fittings is to increase the buckling stress by only 5 per cent. or so in the case of the alloys studied. If $(2a/r)$ is less than 10 the effect of end-fittings is almost negligible; if we formulate a design rule in the form

$$\frac{2a}{r}<10, \quad i.e. \quad \frac{2a}{L}<\frac{10}{(L/r)},$$

then at a slenderness ratio of 40 it would be permissible to support rigidly a quarter of the overall length of the strut.

REFERENCES

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The Twist Due To Bending Moment in Cantilevers Curved in Plan

by

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THE TWIST that arises from bending stresses in straight cantilevers of thin-walled section asymmetrical about any vertical plane, is well known and eventually leads to the concept of a shear centre. If an analysis is made along the same lines as that used for investigating straight beams, of cantilevers curved in plan, it is found that the bending moments transmitted are again responsible for shear stresses in the flanges of the beam and cause twisting.

The following analyses refer, principally, to cases in which the cantilever carries a concentrated load at its end and are confined to the relatively simple forms of the channel and I-section. Each cantilever is perfectly built-in at one end and, for simplicity, it is considered that the web of a section offers no resistance to bending and that the beams are of constant curvature in plan.

The effect of curvature is to provide fibres in the beam flanges which, although subtending the same angle at the centre of curvature, have lengths proportional to their radii and so give varying areas over which excess bending stress is taken. It is for this reason that an apparently symmetrical form, the I-section, may have a virtual shear centre and so be subject to twist due to bending as well as twist due to the torque from the applied load.

The results obtained are derived from the usual elementary stress analysis and take no account of strain compatibility. For this reason the magnitude of the values obtained for the large curvatures may not be very reliable but they should provide reasonably good indications of the order of effect attributable to curvature. The results are also of interest in revealing non-linear distributions of shear stress through the flanges as well as dissimilar stress distributions for inner and outer flanges.

1(*a*). CHANNEL SECTION OPEN TOWARDS CENTRE OF CURVATURE

Consider a thin-walled channel section as shown in Fig. 1 which is curved in plan such that the web describes the arc of a circle of radius R, as in Fig. 2. Assume that only the flanges resist the applied bending moment, M, so that, the normal stress on the section due to bending is given by

$$p=M/(2ath). \quad . \quad . \quad . \quad (1)$$

Consider next an element from say, the top flange of width x, in isolation as shown in Fig. 3, from between radii $OA'A$ and $OB'B$ which enclose a small angle $\delta\theta$. A shear stress q is required along the surface whose trace is $A'B'$, and which is of length $(R-a+x)\,\delta\theta$, to provide equilibrium because of the increase in bending stress in the flange in moving from radial plane OA to OB. Thus,

$$x\delta p=(R-a+x)\,q\delta\theta$$

and

$$q=\frac{x}{R-a+x}\frac{dp}{d\theta}$$

$$=\frac{x}{R-a+x}\frac{dp}{dM}\frac{dM}{d\theta}$$

$$=\frac{x}{R-a+x}\frac{1}{2ath}\frac{dM}{d\theta} \quad . \quad . \quad (2)$$

using equation (1).

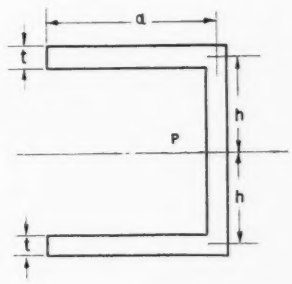

FIGURE 1. Channel section dimensions.

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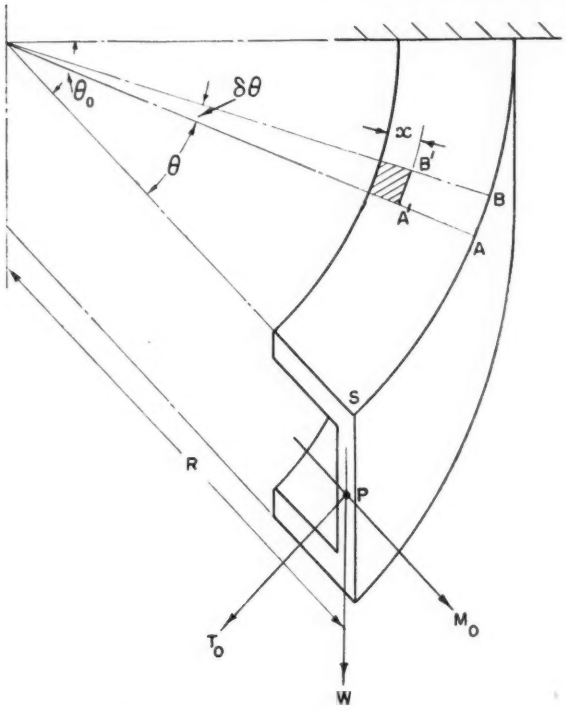

FIGURE 2. Channel section cantilever curved in plan, with $n=1$, facing inwards.

The complementary shear stress acting on the flanges of the section gives rise to a shear flow, and the twisting moment about P due to this is,

$$T=2h\int_0^a qtdx.$$

Substituting from equation (2) and simplifying,

$$T=2h\int_0^a \frac{x}{R-a+x}\,\frac{1}{2ath}\,\frac{dM}{d\theta}\,tdx$$

$$=\frac{1}{a}\,\frac{dM}{d\theta}\int_0^a\left(1-\frac{R-a}{R-a+x}\right)dx$$

$$=\frac{dM/d\theta}{a}\left[a-(R-a)\log_e\left(R/(R-a)\right)\right]$$

$$=dM/d\theta\,[1+(1/y-1)\log_e(1-y)] \qquad (3)$$

$$=dm/d\theta\ .\ f(y)$$

when $y=a/R$ and $f(y)=1+(1/y-1)\log_e(1-y)$.

If the beam carries at its end, at radius nR, a load W acting vertically downwards, and a bending moment M_0 and a twisting couple T_0, (vectorially represented in Fig. 2), then across section $OA'A$ the total bending moment is,

$$M=WnR\sin\theta-T_0\sin\theta+M_0\cos\theta$$

and

$$\frac{\partial M}{\partial\theta}=(WnR-T_0)\cos\theta-M_0\sin\theta. \qquad (4)$$

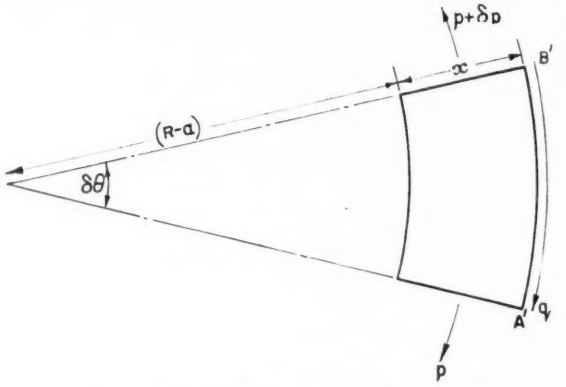

FIGURE 3. Stresses on an element in a flange.

Thus the twisting couple due to bending, by substituting in (3) from (4) is,

$$T=[W(nR-T_0)\cos\theta-M_0\sin\theta]\,f(y)$$

$$=We, \text{ say, if}$$

$$e=\left[\left(nR-\frac{T_0}{W}\right)\cos\theta-\frac{M_0}{W}\sin\theta\right]f(y). \qquad (5)$$

The quantity, e, is a virtual shear centre distance for the section at radius OA.

Taking, $M_0=T_0=0$, equation (5) reduces to

$$e=nR\cos\theta\,f(y)$$

and noting that $e=e_0=\frac{a}{2}$ for a straight beam,

$$e/e_0=(2n/y)\,f(y)\cos\theta \qquad (6)$$

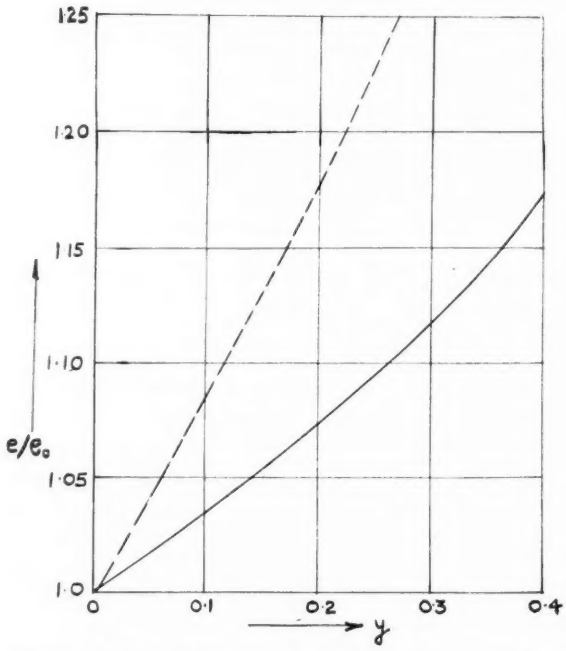

FIGURE 4. Effect of curvature on the ratio e/e_0, channel facing inwards, for $n=1$, ———— and $n=(1+y/2)$, — — —

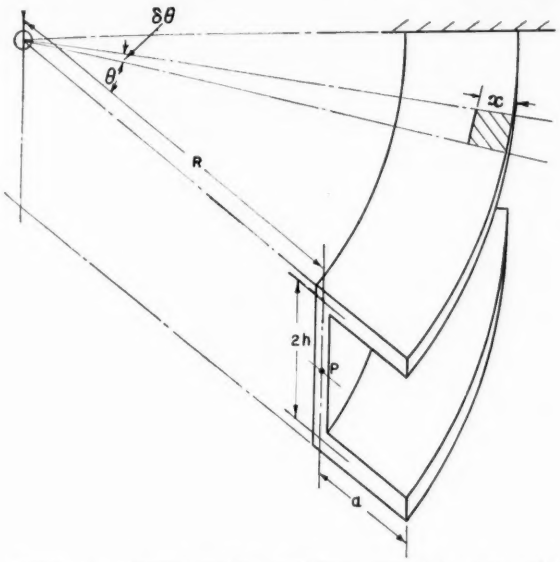

FIGURE 5. Channel section cantilever curved in plan, with $n=1$, facing outwards.

The variation of e/e_0 or $(2n/y)\,f(y)$ with y is shown in Fig. 4, for $n=1$, *i.e.* when the load acts vertically downwards through the web and for $n=1+y/2$, *i.e.* when placed at one half the flange width farther out than the web. It is easily shown that for small values of θ and y

$$e/e_0 \simeq n\,(1+y/3+y^2/6). \quad . \quad . \quad (7)$$

1(*b*). CHANNEL SECTION OPEN AWAY FROM CENTRE OF CURVATURE

When the thin-walled channel section faces outwards from O as in Fig. 5, it is clear by comparison with the case in 1(*a*), that the shear stress due to bending in the flanges is given by,

$$q' = \frac{x}{R+a-x}\,\frac{1}{2ath}\,\frac{dM}{d\theta} \quad . \quad . \quad (8)$$

x being the distance of the section from the outermost fibre of the section.

Using (8) to determine the twisting moment about P,

$$T = 2h\int_0^a q'tdx$$

$$= dM/d\theta\, g\,(y)$$

when $y=a/R$ and $g\,(y)=(1/y+1)\,.\,\log_e(1+y)-1$. The analogue to equation (6) is thus

$$e/e_0 = (2n/y)\,g\,(y)\cos\theta. \quad . \quad . \quad (9)$$

The variation of e/e_0 or $(2n/y)\,g\,(y)$ with y is shown in Fig. 6 for $n=1$ and $n=1+y/2$, the load acting as described in connection with Fig. 4.

Again, for small values of θ and y,

$$e/e_0 \simeq (1-y/3+y^2/6)\,n. \quad . \quad . \quad (10)$$

2. I-SECTION

If each flange is width a, and thickness t and depth $2h$,

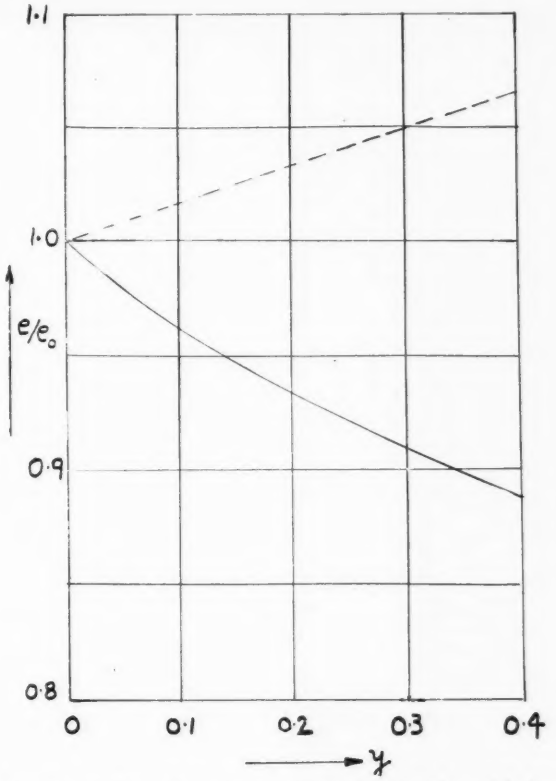

FIGURE 6. Effect of curvature on the ratio e/e_0, channel facing outwards, for $n=1$, ———— and $n=(1+y/2)$, — — —

it follows from Sections 1(*a*) and 1(*b*), that the twisting moment T about the section centre P, due to shear flow is

$$T/(2ht) = \int_0^a q\,dx - \int_0^a q'dx.$$

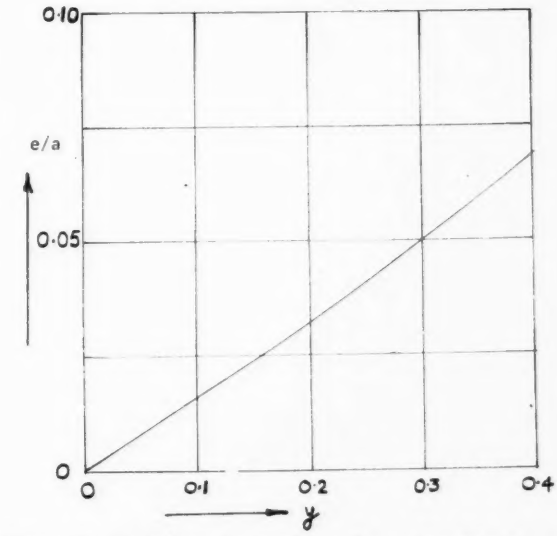

FIGURE 7. Variation of e/a with y for an I-section beam.

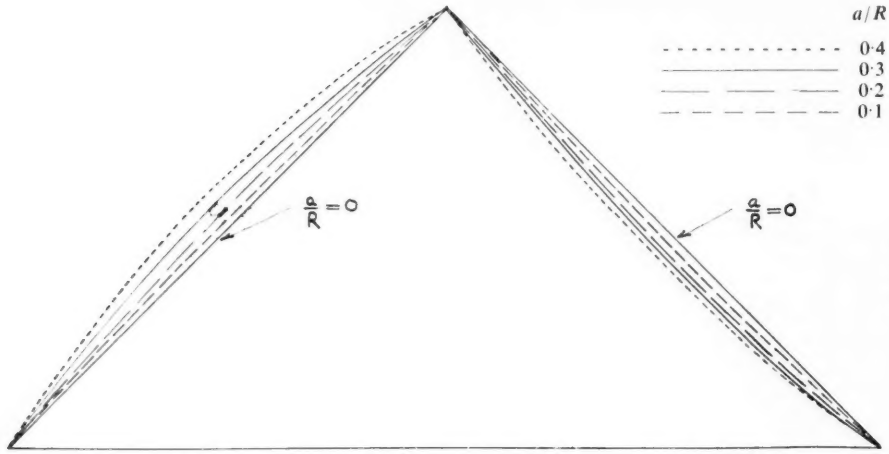

FIGURE 8. The effect of curvature on the distribution of shear stress due to bending in the flanges of an I-section beam.

On substituting for q and q'

$$T=\frac{1}{2a}\cdot\frac{dM}{d\theta}\cdot\left[\int_0^a\left(2-\frac{R-a}{R-a+x}-\frac{R+a}{R+a-x}\right)dx\right]$$

$$=\frac{1}{2a}\frac{dM}{d\theta}\,h(y) \qquad . \quad . \quad . \quad . \quad . \quad (11)$$

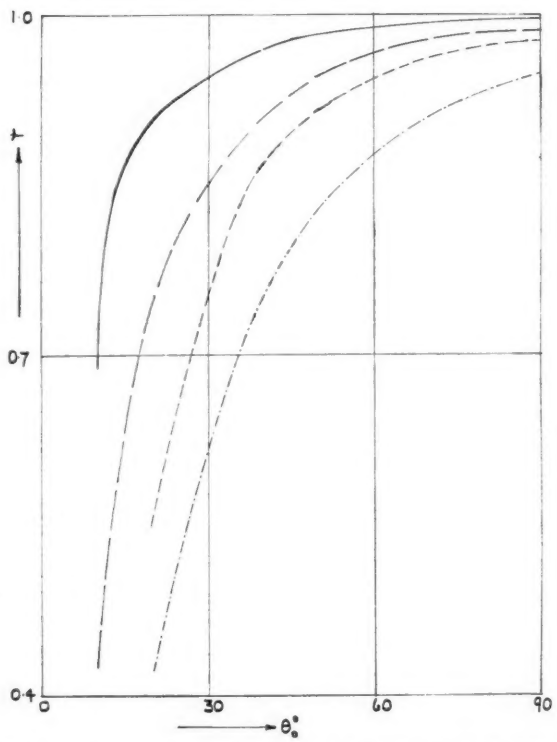

FIGURE 9. Variation of the ratio, total twist without that due to bending to that with twist due to bending, r, for an I-section beam with θ_0, for

$a/R=0{\cdot}1$ ——————
$=0{\cdot}2$ — — — —
$=0{\cdot}3$ — — — — — —
$=0{\cdot}4$ — · — · —

where

$$h(y)=f(y)-g(y)=2-\frac{1}{y}\log_e\frac{1+y}{1-y}-\log_e(1-y^2).$$

If the end load is assumed to be due to W only and to be acting through the vertical mid-plane of the web, then on substituting for $dM/d\theta$ and writing $T=We$, it is found that

$$e=R\,h(y)\cos\theta/2$$

or $$2e/a=h(y)\cos\theta/y \qquad . \quad . \quad . \quad (12)$$

where e is measured away from the web outwards from θ. The variation of e/a with y is shown in Fig. 7. If both y and θ are small,

$$2e/a=\frac{h(y)}{y}=y/3+y^3/10. \qquad . \quad . \quad (13)$$

This result could of course be obtained more directly using equations (7) and (10).

The shear stress q due to the bending stress in the flanges when the cantilever carries W only is obtainable from equations (2) and (8); and if the stress shear at any section, x, when the beam is straight is q_0, then,
(*i*) in the inner flanges,

$$q_0/q=1-y(1-x/a)$$

and (*ii*) in the outer flanges,

$$q_0/q=1+y(1-x/a).$$

The variation of q/q_0 with y, or a/R, over the whole of the upper flange is shown in Fig. 8.

3. COMPARISON OF THE TWIST DUE TO BENDING AND THE APPLIED TORQUE BY A LOAD AT THE END OF A PLANE CURVED CANTILEVER

In Fig. 2, ST represents the mid-plane of the web of an I-section cantilever as seen in plan and the clockwise twisting moment at section OA, C_T, due to the applied load, W, placed at a distance R from O as shown, is,

$$C_T=WR(1-\cos\theta).$$

The clockwise twisting moment on the section due to bending, C_B or We, is given by equations (10) or (11).

The total torque on the section is thus,

$$W\{e+R(1-\cos\theta)\},$$

and hence the twist of the end of the beam relative to the fixed end, is proportional to

$$\int_0^{\theta_0} R\,[e+R\,(1-\cos\theta)]\,d\theta$$

$$=R\int_0^{\theta_0}\left[\left(\frac{a}{2y}f(y)-R\right)\cos\theta+R\right]d\theta$$

$$=R\left[R\theta_0-\left(R-\frac{a}{2y}f(y)\right)\sin\theta_0\right] \quad . \quad (14)$$

If the effect of twisting due to bending had been neglected then the twist would have been proportional to

$$R^2\,[\theta_0-\sin\theta_0]. \quad . \quad . \quad . \quad (15)$$

The departure of the ratio of (15) to (14), r, from unity, gives a measure of the importance of the twist due to bending.

$$r=\frac{\theta_0-\sin\theta_0}{\theta_0-\sin\theta_0+f(y)\sin\theta_0/2},$$

$$\text{or} \quad =\frac{1}{1+f(y)\sin\theta_0/[2\,(\theta_0-\sin\theta_0)]}.$$

The variation of r with θ_0 for certain values of y is shown in Fig. 9. For a given value of y and W, Fig. 10 shows how the absolute values of the total angle of twist, with and without twist due to bending, compare, as the angle subtended by the beam varies,

i.e. $\theta_0-\sin\theta_0+f(y)\sin\theta_0/[2\,(\theta_0-\sin\theta_0)]$.

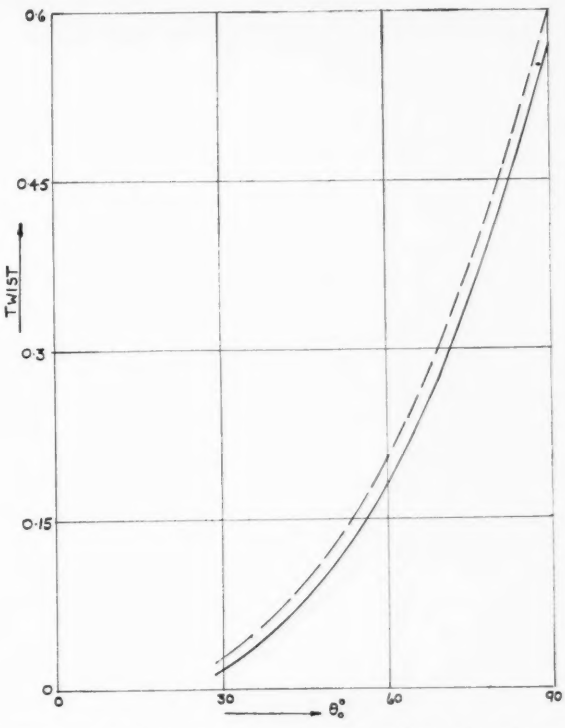

FIGURE 10. Measures of total twist, without that due to bending ————, with that due to bending — — — —, for $a/R=0{\cdot}4$ for an I-section beam, for various values of θ_0.

CONCLUSIONS

1. The effect of beam curvature on the shear stress in the flanges of a beam, is to increase or decrease that shear stress above that obtaining for a similar section straight beam, according as the flange radius is less than, or greater than, the web radius, respectively; this increase or decrease is however not very large even for heavy curvatures.
2. A virtual shear centre exists for beams curved in plan and its magnitude (or position) among other things, is a function of the curvature, being greater the greater the curvature.
3. Curved I-section beams are subject to twist due to bending, this effect being the more pronounced the greater the curvature and the smaller the angle subtended by the beam.

ACKNOWLEDGMENT

The author wishes to acknowledge useful discussions on the subject with Mr. C. Osgerby.

Natural Frequencies of Constant Thickness Cantilever Triangular Plates of Arbitrary Plan Form

by

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SIMPLE FORMULAE are presented for the first three bending-type and the first torsion-type natural frequencies of any constant thickness cantilever triangular plate. The formulae are derived by a semi-empirical method. Comparison of calculated frequencies with test values indicates agreement within a few per cent. for a variety of plate plan forms.

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METHOD

Precise analytical expressions for the natural frequencies of arbitrarily shaped cantilever triangular plates are extremely difficult to derive on a purely theoretical basis. Therefore the problem is solved by the following semi-empirical approach.

The theoretical equation for the natural frequencies of any constant thickness plate may be written:

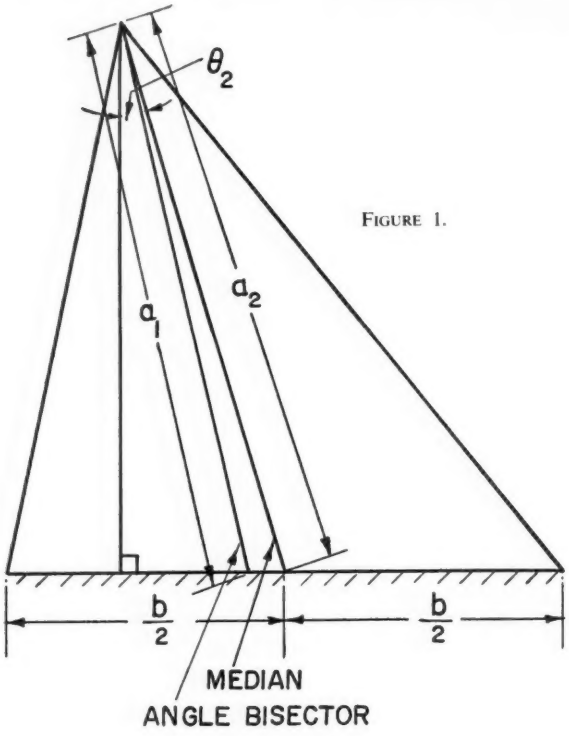

FIGURE 1.

$$f = \frac{k}{2\pi d^2}\sqrt{\left(\frac{D}{\rho t}\right)} \quad . \quad . \quad . \quad (1)$$

where

- f a natural frequency in cycles per second
- k a parameter dependent upon the plate plan form and boundary conditions
- d some effective plate dimension
- D plate flexural rigidity
- ρ mass density of plate material
- t plate thickness

In the method, d is taken to be either a_1, the angle bisector of the vertex angle, or a_2, the median line drawn from the vertex, as shown in Fig. 1. The parameter k is determined by finding a suitable function of plate geometry so that f fits given test data. Theoretical solutions for the frequencies of isosceles triangular plates are of some aid in arriving at desired values of k[2]. It should be noted that no distinction is made between delta-shaped and swept cantilever plates.

RESULTS

The resulting expressions for d and k are listed for the first three bending-type and the first torsion-type natural frequencies as defined by equation (1):

frequency	d	k
first bending	a_1	$\left(7{\cdot}14 - 0{\cdot}4\,\frac{b}{a_1}\right)\sqrt{(\sec\theta_2)}$
second bending	a_2	$\left[31 - 2\left(\frac{b}{a_1}\right) - 2\sqrt{(\sec\theta_2 - 1)}\right]\sqrt{(\sec\theta_2)}$
third bending	a_2	$\left[73 - 4\left(\frac{b}{a_1}\right)^2\right]\left[1 + \left(\sin\theta_2 - \frac{b}{2a_2}\right)\sqrt{(\sec\theta_2 - 1)}\right]$
first torsion	a_1	$\left\{20\left[1 + 0{\cdot}2\left(\frac{b}{a_2}\right)^2\right]^2 + 30\left(\frac{b}{a_2}\right)\sqrt{(\sec\theta_2 - 1)}\right\}\frac{a_1}{b}$

. . . (2)

COMPARISON WITH TEST

Results of calculations carried out for nine cantilever plates previously tested[1] are shown in Table I together with the test values. Agreement is close in all cases. Since the plates were tested in air, any effects of the inertia of the air were present. Slight increases in the values of the natural frequencies occur if the plates are in a vacuum.

No doubt somewhat different d may be used and different expressions for k may be determined. However, it is believed that the formulae presented here are sufficiently accurate for practical purposes while encompassing the complete range of plate plan form shapes.

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TABLE I

CALCULATIONS AND TEST RESULTS FOR THE NATURAL FREQUENCIES OF VARIOUS CANTILEVER TRIANGULAR PLATES $\frac{1}{2\pi}\sqrt{\left(\frac{D}{\rho t}\right)} = 5{\cdot}82$.

Plate	a_1	a_2	b	b/a_1	b/a_2	$\sec\theta_2$	$\sin\theta_2$	*Bending Type* f_1 *theory*	f_1 *test*	f_2 *theory*	f_2 *test*	f_3 *theory*	f_3 *test*	*Torsion Type* *theory*	*test*
A1	11·75	14·14	20	1·706	1·414	1·414		32·5	32·8	92	91	179	181	164	164
A2	10·82	11·17	10	0·925	0·895	1·117		35·3	34·5	140	136	325	325	192	190
A3	10·37	10·45	6	0·578	0·574	1·045		38·3	38·0	160	161	386	392	245	243
A4	10·18	10·20	4	0·393	0·392	1·020		39·6	39·0	168	165	401	403	330	338
A5	10·05	10·05	2	0·199	0·199	1·005		40·6	40·2	173	172	414	411	598	608
S1	10·00	10·00	10	1·000	1·000	1·000		39·1	38·5	168	169	400	404	167	166
S2	10·30	10·43	10	0·970	0·960	1·043	0·285	37·8	37·8	156	151	365	363	194	186
S3	←						*see A2*								→
S4	11·73	12·21	10	0·852	0·819	1·221	0·574	31·6	32·4	121	120	293	293	179	182
S5	13·33	14·14	10	0·750	0·707	1·414	0·707	26·6	26·3	98	101	255	259	166	171

Free Vibration and Hysteretic Damping

by

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IF THE DEFINITION that hysteretic damping is proportional to displacement but in phase with velocity be accepted, then the free vibration of a simple oscillator may be treated, without ambiguity, using this concept. The apparent anomaly which Dr. Bishop points out in his paper "The Treatment of Damping Forces in Vibration Theory" (November 1955 JOURNAL) arises through confusing three distinct possible mathematical representations of some unspecified vibrating system. These are

(*a*) System with hysteretic damping (as defined)

$$M\ddot{x}+C\left|\frac{x}{\dot{x}}\right|\dot{x}+Kx=f(t). \quad . \quad . \quad (1)$$

(*b*) System with complex stiffness

$$M\ddot{x}+K(1+i\mu)x=f(t). \quad . \quad . \quad (2)$$

(*c*) System with damping force proportional to velocity divided by "frequency" and in phase with velocity

$$M\ddot{x}+\frac{h}{\omega}\dot{x}+Kx=f(t). \quad . \quad . \quad (3)$$

Boundary conditions are implied such that the equations represent an oscillatory system. Also, in equation 3, the "frequency" ω must be suitably defined. In the case of free vibration, with which this comment is concerned, these boundary conditions are specified and, in addition, the meaning of frequency is well established. As Dr. Bishop has pointed out, these three representations, when $f(t)=Fe^{i\omega t}$, each give the same practical answer for the steady-state solution of the problem.

W. Pinsker [1] has pointed out, in this connection, that the velocity and the displacement of a damped free vibration are not $\pi/2$ radians out of phase. Let η radians be the phase angle between this velocity and displacement.

Equations (1), (2), (3), for free vibration, become

(*a*) $$M\ddot{x}+C\left|\frac{x}{\dot{x}}\right|\dot{x}+Kx=0. \quad . \quad . \quad (1a)$$

(*b*) $$M\ddot{x}+K(1+i\mu)x=0. \quad . \quad . \quad . \quad (2a)$$

(*c*) $$M\ddot{x}+\frac{h}{\omega}\dot{x}+Kx=0. \quad . \quad . \quad . \quad (3a)$$

These equations can each have a solution of the form $x=x_0e^{(p+i\omega)t}$ if

$$-1\leqslant\frac{C}{2K}\leqslant 1. \quad . \quad . \quad . \quad (1a)$$

$$\text{all } \mu. \quad . \quad . \quad . \quad . \quad (2a)$$

$$-1\leqslant\frac{h}{K}\leqslant 1 \quad . \quad . \quad . \quad (3a)$$

For damped oscillations $C/(2K)$, μ, h/K should each be positive. Except for equation (2*a*), where the effective stiffness is dependent on the damping force, the frequency predicted for the damped oscillation is, as might be expected, less than the "undamped" frequency.

Equation (1*a*) can be shown to give

$$M\ddot{x}+(Ce^{i\eta}+K)x=0 \quad . \quad . \quad . \quad (1b)$$

or $$M\ddot{x}+K\{1+(\sqrt{(1-g^2)}-1+ig)\}x=0 \quad . \quad (1c)$$

or $$M\ddot{x}+\frac{C}{\sqrt{(p^2+\omega^2)}}\dot{x}+Kx=0 \quad . \quad . \quad . \quad (1d)$$

where $C=K\{2(1-\sqrt{(1-g^2)})\}^{\frac{1}{2}} \qquad -1\leqslant g\leqslant 1$

$$\tan\eta=\frac{\omega}{p}$$

Equations (1*b*), (1*c*), (1*d*) are, of course, three forms of the same equation and give identical results.

The table compares the various representations for free vibration.

Except in the case of harmonic oscillation, which Dr. Bishop has treated in some detail in his paper, the mathematical complexity of these methods of representation make them most unattractive. The only virtue, except of course the pleasure of the exercise itself, in extending any of them to include even the free vibration of a simple oscillator would appear to be that it illustrates their fundamental difference. A final, and perhaps slightly irrelevant, point is that the greatly increased availability and scope of general purpose analogue computors tend to make the concept of viscous damping much more significant.

REFERENCE

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Representation	*Effective Stiffness*	*Decay Rate* p	*Frequency* ω	*Logarithmic Decrement* δ
(1*b*) and (1*d*)	K	$\frac{C}{2\sqrt{(KM)}}$	$\sqrt{\left(\frac{K}{M}\right)}\left\{1-\left(\frac{C}{2K}\right)^2\right\}^{\frac{1}{2}}$	$\frac{2\pi\left(\frac{C}{2K}\right)}{\left\{1-\left(\frac{C}{2K}\right)^2\right\}^{\frac{1}{2}}}$
(1*c*)	K	$-\sqrt{\left(\frac{K}{2M}\right)}\{1-\sqrt{(1-g^2)}\}^{\frac{1}{2}}$	$\sqrt{\left(\frac{K}{2M}\right)}\{1+\sqrt{(1-g^2)}\}^{\frac{1}{2}}$	$\frac{2\pi g}{1+\sqrt{(1-g^2)}}$
(2*a*)	$K\sqrt{(1+\mu^2)}$	$-\sqrt{\left(\frac{K}{2M}\right)}\{-1+\sqrt{(1+\mu^2)}\}^{\frac{1}{2}}$	$\sqrt{\left(\frac{K}{2M}\right)}\{1+\sqrt{(1+\mu^2)}\}^{\frac{1}{2}}$	$\frac{2\pi\mu}{1+\sqrt{(1+\mu^2)}}$
(3*a*)	K	$-\sqrt{\left(\frac{K}{2M}\right)}\left\{1-\sqrt{\left(1-\left(\frac{h}{K}\right)^2\right)}\right\}^{\frac{1}{2}}$	$\sqrt{\left(\frac{K}{2M}\right)}\left\{1+\sqrt{\left(1-\left(\frac{h}{K}\right)^2\right)}\right\}^{\frac{1}{2}}$	$\frac{2\pi\left(\frac{h}{K}\right)}{1+\sqrt{\left\{1-\left(\frac{h}{K}\right)^2\right\}}}$

Received 11th January 1956.

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Reviews

AN INTRODUCTION TO THE THEORY OF AEROELASTICITY. *Y. C. Fung. Galcit Aeronautical Series. John Wiley and Sons, New York, 1955. 490 pp. Illustrated. 84s.*

This is, we believe, the first treatise on aeroelasticity to be published, although flutter, which is the most important theme of aeroelasticity, has been the subject of earlier books, while various other aeroelastic problems have been discussed in books on stability and control, and so on. It is now universally recognised that aeroelasticity is a subject of first-rate importance and the author of this book has therefore helped the aeronautical world in an outstanding way by presenting a connected account of the theory in one volume. The scope of the book is indeed wide, for there are few aspects of aeroelastic theory which are not at least touched on.

The contents of the book are briefly as follows. Chapter I is devoted to preliminaries, such as beam theory, the use of influence coefficients and influence functions and elementary aerodynamics. The title of Chapter 2 is " Some Aeroelastic Problems in Civil and Mechanical Engineering " and the subject matter is mainly the oscillation of " bluff bodies " in a stream of fluid, with special reference to the instability of suspension bridges. Chapter 3 is concerned with the divergence of lifting surfaces; the " semi-rigid assumption " and the use of matrices are introduced here. " Steady-State Aeroelastic Problems in General " is the title of Chapter 4 and the subjects covered are reversal of aileron control, the effect of distortion on lift distribution, tail efficiency, the influence of elastic deformation on the static longitudinal stability of an aircraft and the twisting of propeller blades. Chapters 5, 6 and 7 are devoted to flutter, Chapter 8 to transient loads and gusts and Chapter 9 to " Buffeting and Stall Flutter." The next two chapters are concerned respectively with applications of the Laplace transformation and the general formulation of aeroelastic problems. Chapter 12 gives the fundamentals of non-stationary aerofoil theory, and this is followed by chapters on oscillating aerofoils in two-dimensional flow, first for incompressible and then for compressible flow. The last chapter considers unsteady motions in general and there are four Appendices.

A perusal of the book shows that the author is well informed, that he has a good grasp of his subject and that his exposition is lucid. The treatment of flutter is on the whole satisfactory, although somewhat brief; little is said about control surface flutter, while the aerodynamic theory stops short of three-dimensional motion. However, a thorough treatment of the flutter derivatives of finite wings in all the practically important conditions of flow would itself require an extensive treatise, so the author should not be blamed for restricting his discussion to the two-dimensional case, especially as the book only professes to be an introduction to its subject. The book is almost wholly theoretical, experimental methods are barely mentioned and the " engineering " aspects of the subject are not treated. A valuable feature is the provision of extensive lists of references at the ends of the chapters. These will be very helpful to students, but there is the danger that the sheer length of the bibliographies may lead the reader to suppose that they are complete, which is certainly not so, and the selection sometimes appears arbitrary. For example, the bibliography on suspension bridge oscillation totally omits the important publications of Frazer and Scruton.

We can sum up our impressions by saying that this is a valuable and welcome addition to aeronautical literature which should be consulted by all who are concerned with aeroelastic problems. It is safe to predict that the book will be attentively studied by aeronautical engineers and students in the coming years and only such close scrutiny will show how accurate and reliable the book is in detail.—W. J. DUNCAN.

THE MEN BEHIND THE SPACE ROCKETS. *Heinz Gartmann. Weidenfeld and Nicolson, London, 1955. 185 pp. Photographs. 18s.*

The author of this excellent book was himself one of the pioneers of the liquid-propellent rocket engine, for he held a senior position on such work with the B.M.W. concern in war-time Germany. Since then, he has been a prominent member of the post-war West German rocket society (the Gesellschaft für Weltraumforschung), and has attended all the congresses held in various European cities during the past five years by the International Astronautical Federation. He therefore writes with technical knowledge and authority, and with the added advantage of knowing personally many of the men whose work and lives are described in his book.

By any standards, they are an interesting lot, and the author is to be congratulated on having found a fresh approach to the subject of rocketry and space flight, on which so much has already been written (especially from this more popular angle) during the past decade or so. Even those readers who have no special concern with either rockets or interplanetary travel may be expected to find this particular book rewarding. It reveals the familiar pattern of any great new technological development—first, there always appear the cranks and fanatics at whom the world scoffs, then the early theoreticians and experimenters who still have to face a good deal of ridicule and opposition, but who nevertheless succeed in establishing the whole project on a fairly sound basis. Next come the intermediate applications, usually of a military nature to begin with, and finally the whole subject is taken for granted and becomes very much a part of everyday life, with ramifications in industry, politics and so on.

The only factor of any appreciable novelty in the matter of astronautics (as compared, for example, with aeronautics) promises to be the great influence of the prior imaginative literature on the subject. This influence was also present in the case of flight within the atmosphere, but not to anything like the same extent. In the case of space flight, it has obviously (and on their own admissions) stimulated many of the technical pioneers themselves, and has also made the world at large much more receptive to their ideas. Willy Ley (himself one of the early " rocket men ") recently pointed out that a Disney television film on the subject was seen last year by an estimated audience of 40,000,000 people: he wrote: " prediction is one of the causes of reality. That's true of research. It's also true of science fiction."

The individual chapters in Gartmann's book deal with the German Ganswindt, surely the nearest approach in real life to the popular conception of " a mad inventor," but a man with genuine creative vision for all that; with Tsiolkovski, the remarkable Russian peasant-turned-schoolmaster, who might have become a universally recognised scientific genius if he had sprung from more fortunate

stock, but who nevertheless made his mark at least in this field of space flight; and with the American Goddard and the Rumanian-German Olberth, who are now jointly recognised as the greatest of the early pioneers in this subject. Later sections deal with Valier, who tends to be regarded as not quite respectable because of his publicity-seeking experiments with rocket-propelled cars, sledges and gliders, and with the Austrians Sänger and Zborowski, perhaps the first of the real scientific engineers to interest themselves in the subject. The latter was Gartmann's chief at B.M.W., and many interesting technical details are given, for the first time, about the work carried out there. The achievements of this pair are over-shadowed only by the incredible Wernher von Braun. With his wide range of talents, in physics, engineering, music and languages, as a pilot, and—most obviously—as the leader of a technical team, responsible for the V.2 in Germany and (since the war) for the American "Redstone" missile, he provides perhaps the most interesting chapter of all. The only notable omission is the Frenchman, Esnault-Pelterie, and even he (like Dornberger, Winkler and many others) is dealt with fairly and at some length during the course of various digressions in the main biographies.

The book is well illustrated, with many photographs of the men concerned and the rocket engines and vehicles for which they were responsible; it is strongly recommended, especially to those now working on rocketry of one sort or another, but also to the general reader caring for technical history and the men who make it.—A. V. CLEAVER.

DYNAMIK DES FLUGES—EINFLUSS KLEINER STOERUNGEN (*Dynamics of Flight—The Influence of Small Disturbances*). *W. S. Pyschnow. Translated from the Russian into German by G. Adler. V.E.B. Technik Verlag, Berlin, 1955. 191 pp. Illustrated. Index. (In German.)*

This treatise dealing with the basic dynamics of the aeroplane was originally published in Russian in 1951. For the benefit of German readers behind the Iron Curtain a short introductory note is contributed by O. Everling stating the relevant definitions for static and dynamic stability considerations. The eight chapters of the original deal with the basic aspects of aeroplane motions under the influence of small-amplitude disturbances in normal, preferably rectilinear flight: theory of control in pitch and elements of equilibrium and of static longitudinal stability; basic oscillatory motion in pitch; linearly damped oscillations; velocity-governed pitching oscillations (phugoids and incidence-varying oscillations); determination of tail dimensions; disturbances induced by control movements; higher-order disturbances of the longitudinal stability, giving a graphical method for the damping-factor determination, for small disturbances; short, final chapters deal with the lateral stability of aeroplanes, and the interaction between motions in pitch and in yaw.

This textbook names exclusively Russians as responsible for the state of our knowledge of aeroplane dynamics, and there are no other references to literature. Even the invention of the gyropilot is ascribed to C. Ziolkowsky and to N. S. Shoukowski, and dated from 1898.

Spinning, aerobatic flying and the influence of propulsion are not treated, and turning flight is dealt with on a single page. As an elementary textbook for engineering students it is well written and carefully translated; printing and production are good. Thoughtful readers in Communist East Germany may wonder how the West has contrived to produce practical aeroplanes, considering the exclusiveness of Russian work in this sphere.—A. R. WEYL.

BRAZING MANUAL. *Prepared by the Committee on Brazing and Soldering of the American Welding Society. Published by the Reinhold Publishing Corporation, New York, 1955. 193 pp. Illustrated. 38s.*

This textbook, prepared by a Committee of the American Welding Society concerned with Brazing and Soldering, may justly claim to be a comprehensive manual including up to date information on the brazing of the comprehensive range of metallic materials and alloys now available to industry. The book is the joint product of some 32 representatives of American Government Departments, Research and Industry.

Following an introduction defining the brazing terminology, the first eleven chapters are devoted to different aspects of the brazing procedure, ranging from joint design to type of equipment and usage, types of brazing filler materials, pre-treatment, technique and post-brazing operations and inspection. The first impression is that little space has been devoted to pre-cleaning and service preparation, but this is amply covered under individual sections concerned with the brazing of various alloy groups. Chapters 12-22 are concerned with the brazing methods, filler materials and precautions to be used in dealing with each particular group of alloys, ranging from aluminium and aluminium alloys through 10 groups of alloys, including copper alloys, stainless steels, heat-resistant alloys and high nickel alloys. The final chapter is concerned with safety hazards and health protection and a comprehensive Appendix includes particulars of all the materials concerned. This is particularly useful to the English reader in that it includes not only mechanical strength characteristics but chemical constitution particulars, thus making it possible to correlate the information to British specification materials.

The book is profusely illustrated with photographs, and diagrams depict design aspects, plant and equipment and features to be watched for on inspection and testing. It should prove invaluable to designers, engineers and metallurgists concerned with the joining of metallic materials and may be considered a "must" for every Engineering Laboratory's Technical Library.—G. W. WEEKS.

PRINCIPLES OF METEOROLOGICAL ANALYSIS. *Walter J. Saucier. University of Chicago Press, 1955. 438 pp. Illustrated. 75s.*

It is a sign of the growth of meteorology as a science and profession that books are beginning to appear on special sections of the subject without attempting to cover the whole field. This book by W. J. Saucier is probably the first to be devoted solely to meteorological analysis. It is not easy to say where this subject begins and ends. Roughly, it comprises the co-ordination and plotting of weather observations in a form which enables the state of the atmosphere to be more clearly envisaged; it includes the drawing and interpretation of the surface and upper air charts familiar in the forecast room, the tephigrams and atmospheric cross sections, as well as many other charts less commonly used in forecasting, but becoming accepted tools of meteorological research.

This book deals with all of these. In particular, chapters are devoted to the plotting of individual soundings, cross sections, isobaric charts (surface and upper level), isentropic charts, kinematic analysis of divergence, vorticity and deformation, and tropical analysis. Features of broad-scale analysis such as the zonal index are dealt with as well as local analysis from single station observations. The only important omission is a discussion of errors of

observation and the extent to which analysis should allow for them.

In general, the author has been content to quote without discussion the mathematical formulae which form the basis of the analysts charts and diagrams, but his occasional expositions of dynamical theory (*e.g.* dynamical instability) are among the less convincing parts of the book. Similarly the references to forecasting methods are too sketchy to assist the reader.

With the advent of widespread upper air observations many new techniques of analysis have appeared, and there are wide differences between the methods preferred by different forecast teams around the world. In such a book as the present, one might have looked for a clear-cut point of view—a recommended technique leading to a consistent interpretation of the multitude of diagrams that a meteorologist can draw. Perhaps because the book is based on lectures to students who wished to learn of all current techniques, no clear programme of analysis emerges and no clear theme except the importance of upper air observations and three-dimensional thinking about the atmosphere.

The book is well produced, but the scale of many of the diagrams is so small that important figures cannot be read without a magnifying glass. It has a good index and adequate references. It will prove a useful reference book to the practising meteorologist and may be of value to students as a supplement to personal instruction on meteorological charts.—J. S. SAWYER.

NO PASSING GLORY. *Andrew Boyle. Collins, London, 1955. 384 pp. 16s.*

This biography of Group Captain Cheshire is by a "close personal friend," and the author, understandably, keeps as far as possible to facts and avoids interpretations. Most readers will, I fancy, read the book more in search of clues to Cheshire's real character than to refresh their memories of the events of his life.

In contrast to the meagre details of pre-Service life presented in several recent autobiographies of famous airmen, Mr. Boyle spends eighty pages in describing the youth of Leonard Cheshire. The remainder is devoted in equal parts to his war career and to his subsequent humanitarian ventures and conversion to Roman Catholicism. Since Cheshire is even now only thirty-eight, the author has been able to get first-hand stories from his parents, teachers and Service colleagues. The subject of their comments being alive may have led some to reticence, but enough emerges for the reader to obtain a clear picture of Cheshire's activities. Cheshire's motives are not so clear, and it may well be that even his friends do not understand him.

Cheshire senior was an Oxford don, with enough money to send his son to public school and to Oxford during the nineteen-thirties, when the western world was struggling to avert economic disaster and war. It seems that Leonard Cheshire was oblivious to these issues. He enjoyed tennis, sports cars, liquor and flying with the Oxford University Air Squadron, but the economic and political worries of his contemporaries were not his. Chamberlain's "success" at Munich averted war long enough to force Cheshire to take his Law finals in 1939, but before any decision about a career had to be made, the war was on and Cheshire in the Royal Air Force.

It appears that the war gave him a purpose which had hitherto been lacking. While the war lasted, Cheshire was single-minded. Group Captain and Station Commander at 25; V.C., D.S.O., D.F.C.—his war story is well known. His flight to see the Nagasaki atom bomb explode ended this intensely active period of his life and left him physically and nervously worn out. He was discharged from the R.A.F. early in 1946 with a disability pension for psycho-neurosis.

In the past ten years, he has engaged in a struggle to find a purpose to replace the one taken from him by the ending of the war. This decade of collaboration with other unsettled ex-Servicemen has been, for him, filled with uncertainty and frustration, with world lecturing tours, a vain attempt to rejoin the R.A.F., two years as a test-pilot for Vickers, fruit farming, tuberculosis and conversion to Roman Catholicism. Out of this turmoil, his homes for the chronic sick have survived, while Cheshire, himself a sick man, has the consolation of his faith.

His short life has been a lonely one; there is little said of close friendships. No women seem to have influenced him—true, he was married to a charming and wealthy American early in the war. She gave up the comforts of New York for a spartan life in the villages beside our airfields. Flying came first in Cheshire's life, and his wife returned to America in 1944, sick and neglected. Divorce followed. In 1949, he again became engaged, but broke off the engagement to devote himself completely to his homes for the sick. The only one of his loves which spans the three periods of his career is his flying.—A. H. YATES.

DIE STEUERUNG DES GASWECHSELS IN SCHNELLAUFENDEN VERBRENNUNGSMOTOREN (*The Control of Charge Transfer in High-Speed Internal Combustion Engines*). *W. D. Bensinger. Springer-Verlag, Berlin, 1955. 93 pp. Illustrated. DM.12. (In German.)*

This compact handbook deals with all aspects of valve gear for reciprocating engines. Starting with a consideration of general requirements, the various chapters cover the possible lay-outs of poppet valve gear; the calculation of cam profiles; spring design; mechanical design of valves; camshaft drives by gears, chains and push-rods; piston-controlled ports; rotary and sleeve valves. Many illustrations are given from recent practice. The short bibliography includes papers up to 1954. There is an index.

No other text known to the reviewer covers such a wide range of information on this subject. "Valve Gear Design," by Turkish, the classic text in English, goes deeper, but deals with a few topics only.

The presentation is clear and interesting, and the style simple. The student or junior designer with an elementary knowledge of German would find it easy to read, and very instructive. Particularly valuable are the concise discussions of the merits and demerits of the various possible mechanisms; for example, the reasons for the lack of success of the several forms of rotary valve, so advantageous on paper, are clearly set out. For the specialist, there is perhaps nothing new, but the wide variety of information collected together should stimulate thought.—W. J. D. ANNAND.

PLASTICS PROGRESS 1955. *Edited by Phillip Morgan. Iliffe and Sons Ltd., London, 1955. 432 pp. Illustrated. 50s.*

This book brings together some of the more important developments in the field of Plastics technology. It is based on papers given at the British Plastics Convention held in June 1955. The papers are given in full, which was not possible at the Convention, and there is also a complete record of the discussions. There are nine

chapters: Polymer Structure and Properties, Expanded Plastics, Thermoplastics, Extrusion, Work Study and Productivity, Injection Moulding, Patents, Foundry Resins and Glass-Reinforced Plastics. Many of the papers given at the Convention are based on original investigations and for these papers this book provides the first publication.

Five papers were given on glass-reinforced plastics. Among these papers was an improved technique for the injection of resin into a glass fibre filled mould and this technique is claimed to give high consistency in the products. Other papers on glass-reinforced plastics included an appraisal of their use in automobile construction, their possibilities in chemical engineering, testing problems, and the properties and use of epoxide resin/glass laminates.

SONG OF THE SKY. *Guy Murchie. Secker and Warburg, London, 1955. 404 pp. Illustrated. 21s.*

When the Aeronautical Society was founded, the member who had flown was a rarity. In the first half of this century, however, there was a strong feeling that those engaged in the aircraft industry should fly—and most of them did. Today, the light aeroplane is becoming, in Britain, a museum piece, and a generation is growing up which knows little of the joy of flying.

Guy Murchie is not one of these. He became a pilot in the nineteen-twenties and has since qualified as a meteorologist and navigator. He is at home in the air and writes lovingly of the sky and its inhabitants, the clouds, stars, birds and the aeroplanes and their cargoes. Murchie packs into four hundred pages a wealth of information and anecdote. First, we are told of the problems of navigation, not only in the air but also on the seas, not only of today but in Columbus's time too; next, of the weather, the factor which makes every flight different—everything here from dust to rime and from ozone to jet-streams; finally, of the birds that fly, of the men and their craft, their adventures, achievements and failures.

All this could be most indigestible, but the author, a practised writer and airman, has conveyed most vividly his own delight in the sky around him. Those who have loved flying will relish this book; those of the new generation, who know the sky only from the drawing office window or from an occasional passenger flight, would do well to go flying with Murchie. "Song of the Sky" is not for cover to cover reading but makes an excellent bedside anthology.—A. H. YATES.

THE GENERATION OF ELECTRICITY BY WIND POWER. *E. W. Golding. E. and F. N. Spon, London, 1955. 318 pp. Illustrated. 50s.*

In recent years important work has been done on the possibilities of using wind power for the generation of electricity. The author of this book has played a prominent part in this work, both in Britain (where he is in charge of the Rural Electrification and Wind Power Department of the Electrical Research Association) and in other countries, on behalf of their governments and of the United Nations and its specialised agencies.

The book contains several chapters of interest to aeronautical engineers: the structure of the wind, its behaviour when flowing over hills, the magnitude and measurement of gusts and the correlation of wind data with the probable performance of aero-generators located at chosen sites. There is also a study of the use of wind power through the ages, an account of present-day activities, and a survey of future prospects.

FIFTH SYMPOSIUM (INTERNATIONAL) ON COMBUSTION; COMBUSTION IN ENGINES AND COMBUSTION KINETICS. *Published for The Combustion Institute (Pittsburgh, Pennsylvania) by Reinhold, New York. Chapman & Hall, London, 1955. 802 pp. Illustrated. 120s.*

This large volume contains the 101 papers presented at the Fifth International Combustion Symposium held at the University of Pittsburgh in August-September 1954. Forty five of the papers are on the kinetics of combustion reactions; the remainder cover the combustion of fuel droplets and of solids, propelled burning, special techniques and instrumentation diffusion flames and carbon formation, flame spectra and dissociation energies, and special processes in engines. Eleven invited papers by well-known authorities, discuss unsolved problems in various types of engines and basic kinetic problems, including high temperature kinetics.

KNOW YOUR AIRLINERS. *J. W. R. Taylor. Shell-Mex and B.P. Ltd., 1956. 64 pp. Illustrated. 2s. 6d.*

Mr. J. W. R. Taylor must have a houseful of "identification" material about almost every aircraft in the world. His only difficulty is probably in finding new ways of presenting it. Thanks to an organisation whose profits are not derived from the sale of books, this delightfully illustrated little recognition book is available for a mere half-crown and that buys not only the usual silhouettes but quite beautiful full-page coloured pictures by Roy Cross of the aircraft described.—F.H.S.

SHAWCROSS AND BEAUMONT ON AIR LAW. *Second (Cumulative) Supplement to Second Edition. Butterworth, London, 1955. 414 pp. 42s. (Combined price with book £7 7s.)*

The law stated in the book was intended to be as it was at 31st July, 1950. The intention of this, the Second and Cumulative, Supplement, is to bring the book up to date to the 31st. October, 1955. In view of the paucity of authority from cases decided by the English courts, the authors have cited the more interesting cases decided in the United States and Canada which are fully reported in the U.S. and Canadian Aviation Reports.

AIRCRAFT OF THE UNITED STATES AIR FORCE AND UNITED STATES NAVY. *A. P. and P. A. de Jong. E. O. Beck (Publishers) Ltd. English edition 1955. 84 pp. Illustrated. 3s. 6d.*

Originally published in Holland, this book is devoted to one country's air force and is just another plane-spotter's handbook. As long as new types and marks appear and as long as people are interested in telling one aircraft from another (whether they are likely to see them or not) so will publishers continue to produce such "handbooks" as this.

QANTAS AERIANA. *E. A. Crome. Edited by N. C. Baldwin. Francis J. Field Ltd., Sutton Coldfield, 1955. 195 pp. Illustrated. 20s.*

Although the publishers are essentially a philatelic firm they produce, from time to time, remarkably useful historical surveys. Qantas is of course, the embodiment of airline development from rough pioneering to modern luxury flight, including, for good measure, the difficulties of wartime flying with a particularly rough war on the doorstep. The insertion of details about stamps and covers tends to break the continuity of a story but the detail of the history is adequate compensation to those who use the book as a source of reference.

Additions to the Library

G. K. Batchelor and R. M. Davies, R.M. (Editors). SURVEYS IN MECHANICS: THE G. I. TAYLOR 70TH ANNIVERSARY VOLUME. C.U.P. 1956.

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AERODYNAMICS

Boundary Layer

See also Thermo-aerodynamics

On the laminar boundary layer separation from the leading edge of a thin aerofoil. P. R. Owen and L. Klanfer. A.R.C. C.P. No. 220 (1955).

Low speed wind tunnel tests have shown that when a laminar boundary layer separates from the leading edge of a thin aerofoil at incidence the flow often becomes attached to the surface again some distance downstream. The region of separated flow is called a bubble and its chordwise dimension may vary from a minute fraction of the chord to a length comparable with the chord. It is suggested that the length of bubble (more accurately, its order of magnitude compared with the thickness of the laminar boundary layer at separation) depends primarily on the Reynolds number based on the displacement thickness at the separation point. These observations are used to comment on certain peculiarities in the stalling behaviour of thin swept-back wings.—(1.1.4 × 1.10.2.1).

Measurement of skin friction using surface tubes. J. N. Hool. A.R.L. Aero Note 144 (*June* 1955).

The surface tube technique devised by T. E. Stanton is extended to measure the intensity of skin friction. A simple surface tube is described and a method of varying the surface tube calibration curves to cover other fluids and temperatures is developed. An empirical equation is obtained permitting values of the intensity of skin friction to be determined from surface tube-static tapping readings and the width of the opening of the surface tube.—(1.1.0 × 1.12.0).

Empirical relationships for local coefficients of skin friction in sub-sonic air streams. J. N. Hool. A.R.L. Aero Note 145 (*June* 1955).

Some of the better known skin friction equations are compared with experimental results found in turbulent two-dimensional subsonic air flow under a rising pressure gradient. The effects of heat transfer on skin friction under a rising pressure gradient are also considered.—(1.1.0).

An experimental investigation of the effect of surface roughness on the drag of a cone-cylinder model at a Mach number of 2·48. *J. H. T. Wade. U.T.I.A. Report No.* 34 (*September* 1955).

Experimental results are presented to show the effect of surface roughness on skin friction. Average skin friction coefficients were obtained, in the absence of appreciable heat transfer for the turbulent flow along the cylindrical portion of a cone-cylinder model at zero angle of attack. The force measurements were made at $M=2{\cdot}48$ and $Re=4{\cdot}9$ million, using an internal strain-gauge balance. The roughness effects were produced by cutting a vee-thread into the surface of the cylinder and covered a range from 6 to 10,000 microinches (peak-to-valley height).—(1.1.0).

Lift hysteresis at stall as an unsteady boundary-layer phenomenon. F. K. Moore. N.A.C.A. T.N. 3571 (*November* 1955).

With the problem of rotating compressor stall in view, an unsteady boundary layer calculation is made to find the unsteady increment of lift of a stalled elliptic aerofoil in a flow of time-dependent incidence. The analysis indicates a counter-clockwise hysteresis loop of the lift curve, the various forms of which are discussed.—(1.1.1).

Pressure rise associated with shock-induced boundary-layer separation. E. S. Love. N.A.C.A. T.N. 3601 (*December* 1955).

Some recent contributions to the problem of shock-induced separation of the boundary layer are examined, and additional analytical and experimental results are presented. The probable ranges of pressure rises and flow deflections associated with separation are indicated. Consideration is given to the effects of Mach number, adverse pressure gradient, and Reynolds number for laminar boundary layers and to the effects of Mach number, Reynolds number, and ratio of specific heats for turbulent boundary layers.—(1.1.4.4).

Compressible Flow

Bericht über eine Näherungstheorie der Strömung um Rotationskörper ohne Anstellung bei Machzahl Eins. F. Keune. D.V.L. Bericht Nr. 3 (*December* 1955).—(1.2.2).

Flight investigation at Mach numbers from 0·8 *to* 1·5 *to determine the effects of nose bluntness on the total drag of two fin-stabilized bodies of revolution. R. G. Hart. N.A.C.A. T.N.* 3549 (*December* 1955).

Values of total drag coefficient were measured for two fin-stabilised, blunt-nosed bodies of revolution in free flight at Mach numbers from 0·8 to 1·5. The blunt nosed bodies were designed by rounding off the sharp noses of bodies, having nose fineness ratios of about 3-1/2, to radii equal to about one-fourth the maximum radii. No increase in the drag of either body was found.—(1.2.2).

Fluid Dynamics

Pressure distributions; axially symmetric bodies in oblique flow. I. J. Campbell and R. G. Lewis. A.R.C. C.P. No. 213 (1955).

A simple picture, known from the work of I. Lotz, of the flow over the forward part of a body of revolution in oblique flow is derived here from entirely elementary considerations. The pressure at any point of the (forward part of the) body at any angle of incidence depends on three parameters whose values vary along the body. The variation of these parameters along the body can be determined from a relatively small number of wind tunnel or water tunnel measurements. The necessary water tunnel measurements have been made for four axially symmetric head shapes.—(1.4).

Contribution a l'étude des milieux poreux. M. M. Boreli. Pub. Sc. et Tech., No. 305 (1955).—(1.4.1).

Vortex interference on slender airplanes. A. H. Sacks. N.A.C.A. T.N. 3525 (*November* 1955).

Formulae are developed for the forces and moments due to vortex interference on a slender wing-body-tail combination of general cross section performing quasi-stationary manoeuvres. It is found that in steady straight flight the interference lift depends only on the impulse of each shed vortex and its image vortex in a transformed circle plane, this quantity to be determined at the wing trailing edge and at the base of the configuration.—(1.4.3).

Impingement of water droplets on a sphere. R. G. Dorsch et al. N.A.C.A. T.N. 3587 (*November* 1955).

Droplet trajectories about a sphere in ideal fluid flow were calculated. From the calculated droplet trajectories, the droplet-impingement characteristics of the sphere were determined. Impingement data and equations for determining the collection efficiency, the area, and the distribution of impingement are presented in terms of dimensionless parameters. The range of flight and atmospheric conditions covered in the calculations was extended considerably beyond the range covered by previously reported calculations for the sphere.—(1.4).

Internal Flow

Performance and boundary-layer data from 12° *and* 23° *conical diffusers of area ratio* 2·0 *at Mach numbers up to choking and Reynolds numbers up to* $7{\cdot}5 \times 10^6$. *B. H. Little, Jr., and S. W. Wilbur. N.A.C.A. Report* 1201 (1954).

For each of two inlet boundary layer thicknesses, performance and boundary layer characteristics have been determined for a 12°, 10 in. inlet diameter diffuser, a 12°, 21 in.

NOTE.—*The figures in parenthesis at the end of each Summary are for office use only.*

inlet diameter diffuser, and a 23°, 21 in. inlet diameter diffuser. The investigation covered an inlet Mach number range from about 0·10 to the choking Mach number. The corresponding Reynolds numbers, based on inlet diameter, varied from about $0{\cdot}5 \times 10^6$ to $7{\cdot}5 \times 10^6$.—(1.5.1.1).

Charts of boundary-layer mass flow and momentum for inlet performance analysis: Mach number range, 0·2 to 5·0. P. C. Simon and K. L. Kowalski. N.A.C.A. T.N. 3583 (*November* 1955).

Significant flow parameters for various fractions of a turbulent boundary layer are presented in chart form for a number of power-law velocity profiles and a range of Mach numbers up to 5·0. Estimates of auxiliary inlet mass flow or momentum may easily be made. Application of the charts to inlets of arbitrary shape and to the determination of the pressure recovery of rectangular normal shock inlets immersed in boundary layer is described.—(1.5.1).

PERFORMANCE ESTIMATION

The problem of reducing the speed of a jet transport in flight. D. D. Davis, Jr. N.A.C.A. T.N. 3613 (*December* 1955).

The distance required to decelerate a high-speed jet transport from the normal operating speed to the design speed for maximum gust intensity (rough-air speed) has been calculated for the case of level flight with the engines idling. This distance was found to be much greater for a jet transport than for a typical piston-engined transport at the same altitude, and the distance was found to increase with altitude up to the altitude for maximum true air-speed.—(1.7).

STABILITY AND CONTROL

A study of the problem of designing airplanes with satisfactory inherent damping of the Dutch roll oscillation. J. P. Campbell and M. O. McKinney, Jr. N.A.C.A. Report 1199 (1954).

Some preliminary results are given of a theoretical investigation to determine what design features appear most important in designing modern high-performance aeroplanes to have the greatest possible inherent stability of the Dutch roll oscillation so that the need for artificial stabilising devices can be minimised. These preliminary results cover the case of fighter aeroplanes at subsonic speeds.—(1.8.1).

Application of several methods for determining transfer functions and frequency response of aircraft from flight data. J. M. Eggleston and C. W. Mathews. N.A.C.A. Report 1204 (1954).

Several methods for determining the transfer functions and frequency response of aircraft from flight tests are given. Results obtained from experience in the use of these methods are compared as to time required for application, comparative accuracy, and means for facilitating their use. The studies cover three categories of methods: sinusoidal response, Fourier analysis of transients, and curve-fitting analysis of transients. Three general types of aircraft are used to illustrate the application of these methods.—(1.8.2).

Experimental investigation at low speed of effects of fuselage cross section on static longitudinal and lateral stability characteristics of models having 0° and 45° sweptback surfaces. W. Letko and J. L. Williams. N.A.C.A. T.N. 3551 (*December* 1955).

An experimental investigation was made at low speed to determine the effects of fuselage cross section on the static longitudinal and lateral stability characteristics of aeroplane models having 0° and 45° swept-back surfaces. The results indicate that the shallow-fuselage configurations are the least stable longitudinally, and the deep-fuselage configurations are the least stable directionally.—(1.8.0).

Laboratory investigation of an autopilot utilizing a mechanical linkage with a dead spot to obtain an effective rate signal. E. C. Seaberg. N.A.C.A. T.N. 3602 (*December* 1955).

The results of a laboratory investigation of a front-lash auto-pilot are presented. The operation of this auto-pilot is based on the non-linear principle of utilising a dead spot in the servo-motor feed-back linkage to the gyroscope base reference as a means of obtaining a leading control signal. The investigation consists of oscillating-table tests to determine the effect of frontlash on the amplitude and phase responses of the system. Roll-simulator tests were also conducted.—(1.8).

Theoretical span load distributions and rolling moments for sideslipping wings of arbitrary plan form in incompressible flow. M. J. Queijo. N.A.C.A. T.N. 3605 (*December* 1955).

A method is presented for determining the span load distribution and rolling moment due to sideslip for wings of arbitrary plan form in incompressible flow. The method was used to prepare charts from which the rolling moment due to sideslip can be obtained for wings having a large variety of aspect ratio, sweep, and taper ratio. Calculated values of span loads and rolling moments are compared with those of other theories and with experimental results.—(1.8.1.2).

THERMO-AERODYNAMICS

Heat transfer in slip flow. R. L. Martino. U.T.I.A. Report No. 35 (*October* 1955).

The Rayleigh approach was employed in a theoretical investigation of the effect of slip and temperature jump on the heat transfer characteristics of a flat plate in a compressible laminar flow for a constant initial surface temperature. The heat transfer parameters were matched to the Chapman-Rubesin results for steady flow in the continuum régime.—(1.9.1).

Laminar separation over a transpiration-cooled surface in compressible flow. M. Morduchow. N.A.C.A. T.N. 3559 (*December* 1955).

A theoretical analysis of laminar separation in compressible flow over a transpiration-cooled surface maintained at a uniform wall temperature is made. A simple method of calculating the separation point over such a surface for a given adverse pressure gradient, Mach number, wall temperature, and uniform coolant temperature is developed. A numerical example shows the effects of these parameters on the separation point.—(1.9 × 1.1.4).

Free-convection effects on heat transfer for turbulent flow through a vertical tube. E. R. G. Eckert et al. N.A.C.A. T.N. 3584 (*December* 1955).

Experimental heat-transfer data for the turbulent flow of fluids through stationary vertical tubes with both small and large length-to-diameter ratios (to 40) are compared. The limits of the different flow regions, originally established for a tube with small length-to-diameter ratio, apply on the basis of existing data for a tube with large length-to-diameter ratio.—(1.9).

Summary of laminar-boundary-layer solutions for wedge-type flow over convection- and transpiration-cooled surfaces. J. N. B. Livingood and P. L. Donoughe. N.A.C.A. T.N. 3588 (*December* 1955).

The solutions presented were determined for conditions prevailing over cooled turbine blades. The principal results are restricted to a Prandtl number at the wall of 0·7 and are presented for large temperature changes through the boundary layer adjacent to a constant temperature wall and for small temperature changes through the boundary layer adjacent to a wall of either a constant or a variable temperature. Results from the literature for Prandtl numbers up to 5·0 are discussed for a flat porous plate.—(1.9.1).

Turbulent-heat-transfer measurements at a Mach number of 0·87. *M. J. Brevoort and B. Rashis. N.A.C.A. T.N.* 3599 (*December* 1955).

An axially symmetric annular nozzle was used to obtain essentially flat plate data on turbulent heat transfer coefficients and temperature recovery factors for a Mach number of 0·87 and for a Reynolds number range from $9{\cdot}88 \times 10^6$ to $2{\cdot}09 \times 10^8$.—(1.9.1).

WINGS AND AEROFOILS

See also BOUNDARY LAYER

*Further flight tests on a Vampire aircraft fitted with turbulence strips. A. A. Keeler. A.R.L. Note F.*24 (*September* 1955).

Quantitative flight tests have been made on Vampire A87-2 at altitudes of 10,000 and 35,000 ft., to determine the

increase in $C_{L\max}$ with turbulence strips fitted to the outboard portions of the wings.—(1.10.2.2).

Contribution expérimentale a l'étude du profil portant aux vitesses transsoniques. R. Michel and M. Sirieix. O.N.E.R.A. Note Technique No. 26 (1955).—(1.10.2.1).

*Reduction of wing drag due to lift in supersonic flight along a fuselage. R. M. Licher. Douglas Report No. SM-*19257 (*September* 1955).

It is shown that it is possible to reduce the drag due to lift for an isolated wing in supersonic flight by adding a fuselage carrying the proper distribution of lift; this is possible even if the wing by itself has the optimum distribution of lift for its plan form. The optimum fuselage lift distribution, for any given wing lift distribution, is given along with simple upper and lower bounds on the possible drag reductions; one method of calculating the drag of the wing-fuselage combination is outlined.—(1.10.12).

*Reduction of supersonic wave drag for wing-fuselage combinations at zero lift. R. M. Licher. Douglas Report No. SM-*19436 (*November* 1955).

In general, minimum drag for a wing-fuselage configuration does not result from the combination of a wing and a fuselage each of which, as isolated bodies and under given constraints, has minimum wave drag. If the wing geometry is assumed fixed, there exists a relatively simple criterion for determining the optimum fuselage shape. An example of the application of this criterion, selected because of the ease with which it can be treated analytically, is given for fuselages combined with wings having elliptic plan form and optimum thickness distribution.—(1.10.1.1).

A comparison of the spanwise loading calculated by various methods with experimental loadings obtained on a 45° *swept-back wing of aspect ratio* 8·02 *at a Reynolds number of* $4{\cdot}0 \times 10^6$. *W. C. Schneider. N.A.C.A. Report* 1208 (1954).

Experimental force and moment data obtained by pressure measurements on a wing of aspect ration 8·02, 45° sweep-back of the quarter-chord line, taper ratio of 0·45, and N.A.C.A. 63_1A012 aerofoil sections have been compared with the calculated loadings obtained by the standard methods proposed by Weissinger, Falkner, and Multhopp, as well as by several variations of these methods.—(1.10.1.2).

The effect of Reynolds number on the stalling characteristics and pressure distributions of four moderately thin airfoil sections. G. B. McCullough. N.A.C.A. T.N. 3524 (*November* 1955).

Low-speed measurements of the lift, drag, pitching moment, and pressure distribution of the N.A.C.A. 0008, 0007·5, 0007, and 0006 aerofoil sections are presented for Reynolds numbers from 1·5 to 6 million. It is shown that the flow over these sections underwent a change at some value of the lift coefficient which depended on the aerofoil thickness ratio and Reynolds number. The effect of the flow change on maximum lift was small.—(1.10.2.1).

The transonic characteristics of 36 *symmetrical wings of varying taper, aspect ratio, and thickness as determined by the transonic-bump technique. W. H. Nelson et al. N.A.C.A. T.N.* 3529 (*December* 1955).

An investigation was made in the Ames 16 ft. high speed wind tunnel, utilising the transonic bump technique to determine the effects of plan form taper on a series of wings having aspect ratios of 4, 3, and 2, and N.A.C.A. 63A00X sections with thickness-to-chord ratios of 8, 6, 4, and 2 per cent. The Mach number range was 0·6 to 1·1 with a corresponding Reynolds number range of about 1·4 million to 2·0 million.—(1.10.2.2).

Flight investigation at Mach numbers from 0·6 *to* 1·7 *to determine drag and base pressures on a blunt-trailing-edge airfoil and drag of diamond and circular-arc airfoils at zero lift. J. D. Morrow and E. Katz. N.A.C.A. T.N.* 3548 (*November* 1955).

Results of an exploratory free-flight investigation at zero lift of several rocket-powered drag research models having rectangular 6 per cent. thick wings are presented for a Mach number range of 0·6 to 1·7. Wings having diamond, circular-arc, and blunt trailing edge aerofoil sections were tested. Pressures over the base of the blunt trailing edge aerofoil were measured. The drags of all the models were measured and are compared with theory in this paper.—(1.10.2.2).

Impingement of water droplets on N.A.C.A. 65*A*004 *airfoil at* 0° *angle of attack. R. J. Brun and D. E. Vogt. N.A.C.A. T.N.* 3586 (*November* 1955).

The trajectories of droplets in the air flowing past an N.A.C.A. 65A004 aerofoil at an angle of attack of 0° were determined. The amount of water in droplet form impinging on the aerofoil, the area of droplet impingement, and the rate of droplet impingement per unit area on the aerofoil surface were calculated from the trajectories and presented to cover a large range of flight and atmospheric conditions.—(1.10.1.1).

Helicopter Aerodynamics

Method for studying helicopter longitudinal maneuver stability. K. B. Amer. N.A.C.A. Report 1200 (1954).

A theoretical analysis of helicopter manoeuvre stability is made and the results are compared with experimental results for both a single and a tandem rotor helicopter. Techniques are described for measuring in flight the significant stability derivatives for use with the theory to aid in design studies of means for achieving marginal manoeuvre stability for a prototype helicopter.—(1.11.2).

Studies of the lateral-directional flying qualities of a tandem helicopter in forward flight. K. B. Amer and R. J. Tapscott. N.A.C.A. Report 1207 (1954).

Results of flight measurements and pilots' opinion of the forward-flight lateral directional flying qualities of a tandem helicopter in several different configurations are compared and analysed. The conclusions are presented in the form of desirable flying qualities goals applicable to all types of helicopters.—(1.11.2).

Testing and Instruments

See also Boundary Layer

*A method of boundary layer flow visualisation for use in flight. P. B. Atkins and R. S. Trayford. A.R.L. F.*22 (*July* 1955).

A method of wetting the upper surface of a wing prepared with a coating of china clay has been developed in a wind tunnel, and flight tests have shown that the method can be successfully adopted for flow investigations in flight.—(1.12.2).

*Papers presented at the joint session of the flight test techniques and wind tunnel and model testing panels. Ottawa, Canada. A.G.A.R.D. AG*18/*P*8 (*June* 1955).—(1.12.1 × 1.12.2).

Contribution a l'étude de l'effet de paroi en écoulement plan incompressible. J. Barbieux. Pub. Sc. et Tech. No. 304 (1955). —(1.12.1).

Fahrtmesser und Machmeter. H. Sarnow. D. F. L. Bericht Nr. L 45-55/8 (June 1955).—(1.12.2).

Flight calibration of four airspeed systems on a swept-wing airplane at Mach numbers up to 1·04 *by the N.A.C.A. radar-phototheodolite method. J. R. Thompson et al. N.A.C.A. T.N.* 3526 (*November* 1955).

The characteristics of four different air speed systems installed in a swept-wing aeroplane have been investigated in flight up to 1·04 Mach number by the N.A.C.A. radar-phototheodolite method of air speed calibration. The variations of static-pressure defect per unit indicated impact pressure with Mach number and a limited amount of information on the effect of aeroplane normal force coefficient are presented for each system. The results are compared with available theory and wind tunnel tests of the isolated heads.—(1.12.2).

DESIGN AND CONSTRUCTION

The influence of turbojet airflow on the aerodynamic design of airplanes. H. Luskin and H. Klein. Douglas Report No. SM-19111 (June 1955).

Some aspects of the effects of turbo-jet air flow on aerodynamics of aeroplanes are discussed. The momentum and angular momentum theorems are used to find the longitudinal forces and the moments acting on a turbo-jet aeroplane. Consideration of the forces shows the thrust force to be strongly affected by inlet pressure recovery at supersonic speeds. Other, less important, effects on longitudinal forces are also studied. The moments are discussed in connection with correction of power-off model data to power-on characteristics. Inlet particle aspiration; buffeting, heating, and noise of jets; and non-uniformity of flow into the inlet are also taken up briefly.—(4.2).

MATERIALS

A refined heat treatment method for steel fatigue specimens. M. M. Hutchison and F. E. Beissel. A.R.L. Met. Note 3 (August 1955).

An experimental procedure is described whereby Moore-type fatigue test specimens of S.A.E. 4140 steel can be hardened and tempered after surface finishing without any alterations of the surface profile, surface structure and composition of the steel. A modification of the taper sectioning technique is used for examining the surface.—(21.5).

The chromium-rich alloys of the chromium-titanium-tungsten system at 900° and 1200°C. N. Ryan. A.R.L. Report Met. 13 (July 1955).

Isothermal sections at 900°C. and 1,200°C. of the chromium-titanium-tungsten system were studied by metallographic and X-ray methods.—(21.1).

Grain-boundary behavior in creep of aluminum bicrystals. F. N. Rhines et al. N.A.C.A. T.N. 3556 (December 1955).

The gliding of one metal crystal with respect to another parallel to their mutual grain boundary has been studied in pure aluminium bicrystals during isothermal creep at temperatures ranging from 200°C. to 650°C. under static stresses of 10 to 1,600 p.s.i. The motion is spasmodic and begins with an induction period. The mechanism of grain-boundary gliding is described as a co-ordinated alternation of slip and recovery in a chain of subgrains along the creep boundary. This concept is employed to account both for the rate of primary creep and for the transition from primary to steady-state creep.—(21.2.2).

POWER PLANTS

Zur Mechanik der Photonen-Strahlantriebe. E. Sänger. Mitteilungen aus dem Forschungsinstitut für Physik der Strahlantriebe. No. 5 (January 1956).—(27.3).

Acoustic analysis of ram-jet buzz. H. Mirels. N.A.C.A. T.N. 3574 (November 1955).

A one-dimensional analysis of ram-jet buzz is presented. It is assumed that the buzz has a linear instability origin and that the combustion chamber is of constant area. The configuration is shown to be unstable when the real part of the acoustic impedance of the inlet is greater than a term of the order of the combustion chamber Mach number.—(27.4).

Experimental investigation of blade-flutter in an annular cascade. J. R. Rowe and A. Mendelson. N.A.C.A. T.N. 3581 (November 1955).

Compressor type annular cascades of aerofoils were investigated to determine effects on flutter characteristics of varying angle of attack, blade chord and spacing, number of blades, and air velocity. Strain gauge, pressure probe, and hot wire anemometer instrumentation was used. Large amplitude sporadic vibrations in the stall region were encountered and are reported. No rotating stall was observed.—(27.1).

PROPELLERS

A wind-tunnel investigation of the effects of thrust-axis inclination on propeller first-order vibration. W. H. Gray et al. N.A.C.A. Report 1205 (1954).

Data are presented on aerodynamic excitation of propeller vibration with the thrust axis at two angles of inclination to the air stream. Aerodynamic excitation is calculated and compared with measured values for several conditions. Measured and calculated blade vibratory stresses for several excitation values are presented.—(29.1).

Aerodynamic characteristics of a small-scale shrouded propeller at angles of attack from 0° to 90°. L. P. Parlett. N.A.C.A. T.N. 3547 (November 1955).

Tests have been performed to determine the effects of air speed and angle of attack on the lift, drag and pitching moment of a shrouded propeller model, having a shroud length of about two-thirds of the propeller diameter, over an angle of attack range from 0° to 90°. Tests were made of the complete model with the propeller operating and also of the shroud alone with the propeller removed. The effect of inlet lip cross-sectional radius on the static thrust characteristics was also studied.—(29.1).

REFERENCE LITERATURE

Quarterly bulletin. National Aeronautical Establishment, Canada. Report No. N.A.E. 1955(4) (1st October to 31st December 1955).—(30.0).

SCIENCE—GENERAL

A review of aerodynamic noise. L. R. Fowell and G. K. Korbacher. U.T.I.A. Review No. 8 (July 1955).

A detailed review is presented of the theoretical and experimental advances that have been made in the study of aerodynamic noise and in devising means for its suppression. Since many workers in the fields of aerodynamics and aerophysics may be unfamiliar with acoustic principles, the necessary background of laws and ideas from the field of acoustics is included. The theories for noise caused by subsonic disturbances, which may include turbulence fields in overchoked jets, and for those noise sources peculiar to overchoked jets, are considered. Experimental results are quoted with graphs, notes on correlation of data for model and engine jets and a comparison with theory.—(32.2.3).

Introduction a la mécanique des milieux continus. P. A. d'Auriac. Pub. Sc. et Tech. No. 306 (1955).—(32.2).

STRUCTURES

Theory and Analysis

Static strength tests on riveted and bolted structural joints. A. G. Cole et al. A.R.L. Note S.M. 219 (September 1955).

Static tests carried out on typical structural joints showed that the stiffness could be increased considerably by using tensioned high strength bolts in place of mild steel rivets and that the apparent coefficient of friction of two tension specimens appeared to be in the vicinity of 0·5.—(33.2.4.13.1).

Plastic flow in a beam compressed by three dies. W. Freiberger. A.R.L. Report SM. 229 (July 1955).

The plastic bending of a beam bent over a very short span is investigated. Upper and lower bounds for the required pressures are found. The results are applicable to the straightening of beams without introducing high tensile stresses.—(33.2.2).

An analysis of the stiffness and optimum weight-stiffness of tubes with inclined ribs. A. H. Hall. N.A.E. Report 22 (1954).

Expressions are derived for the effective stiffness in bending and in torsion of tubes with inclined ribs, and the condition for optimum weight-stiffness is investigated. It is found that true optimum weight-bending stiffness configurations exist in the conventional wing range but for torsion the optimum condition is beyond applicable limits. Curves are plotted for the relative skin and rib thicknesses for the optimum weight-bending stiffness of certain rectangular tubes, and for the corresponding increases in bending and torsional stiffnesses.—(33.2.3.2).

APPOINTMENTS

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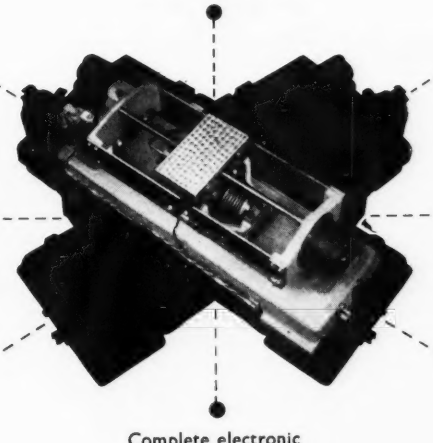
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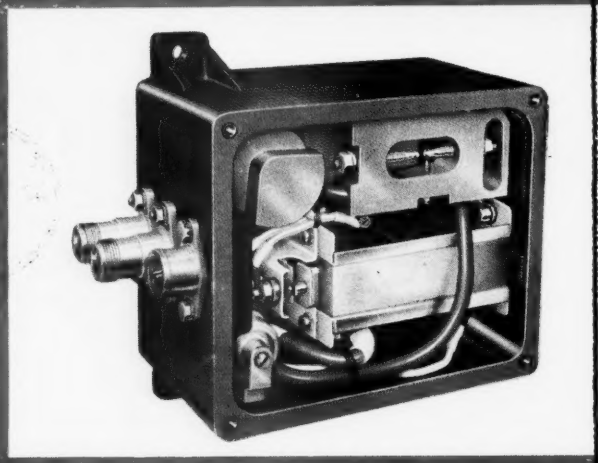

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